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**The effectiveness of Bacillus
thuringiensis, Dimilin, Sumithion
and Matacil against the Hemlock
Looper, Lambdina fiscellaria
fiscellaria, in Newfoundland
in 1985**

A.G. Raske, A. Retnakaran, R.J. West, J. Hudak, K.P. Lim
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THE EFFECTIVENESS OF BACILLUS THURINGIENSIS, DIMILIN, SUMITHION AND
MATACIL AGAINST THE HEMLOCK LOOPER, LAMBDA FISCELLARIA FISCELLARIA,
IN NEWFOUNDLAND IN 1985

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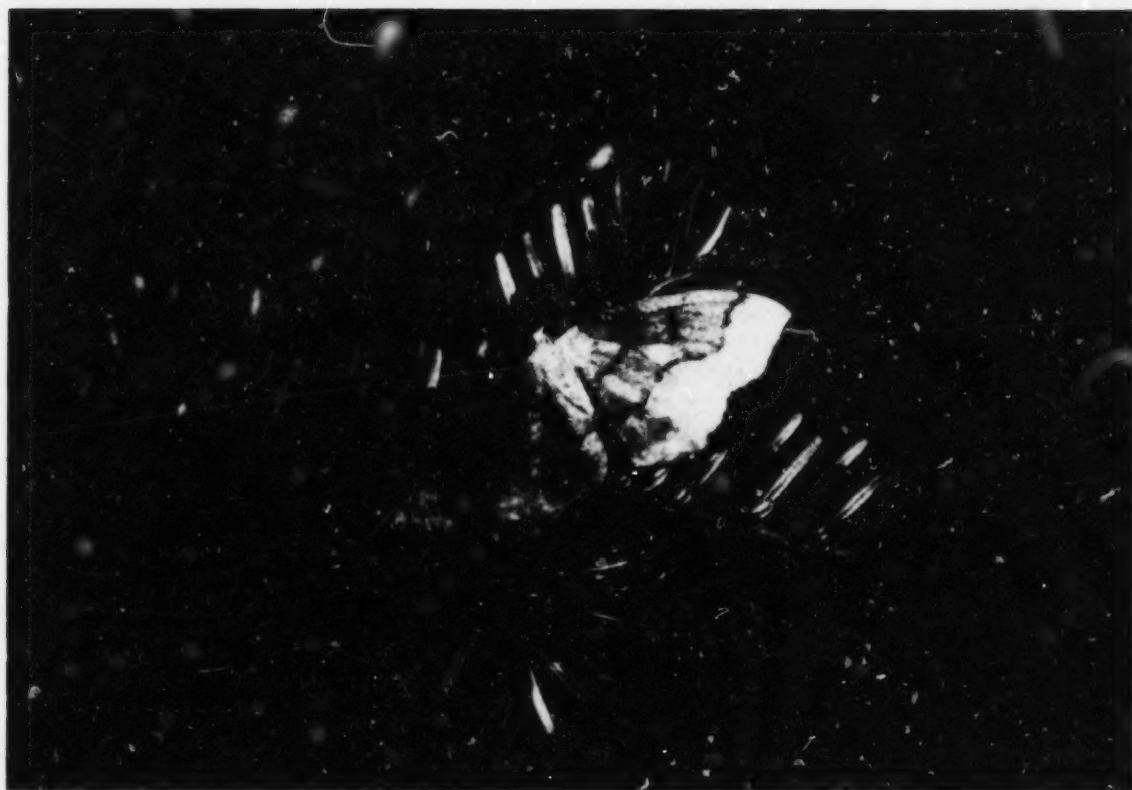
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HEMLOCK LOOPER MOTH

FOREWORD

The experimental sprays described in this report were a joint research project by the Newfoundland Forestry Centre and the Forest Pest Management Institute of the Canadian Forestry Service and the Forest Protection Division of the Newfoundland Department of Forest Resources and Lands. Funding was provided by the Province through Federal-Provincial Forestry Agreements and supplemented by funds from the Canadian Forestry Service, Zoecon Industries Ltd., Sumitomo Chemical America Inc., Duphar B.V. and Chem-Agro Ltd.

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THE EFFECTIVENESS OF BACILLUS THURINGIENSIS, DIMILIN, SUMITHION AND
MATACIL AGAINST THE HEMLOCK LOOPER, LAMBDA FISCCELLARIA FISCCELLARIA,
IN NEWFOUNDLAND IN 1985

ABSTRACT

The effectiveness of aerially applied formulations of Bacillus thuringiensis var. kurstaki (B.t.), Dimilin®, Sumithion®, and Matacil® were tested against the hemlock looper, Lambdina fiscellaria fiscellaria Guen. (Geometridae), in Newfoundland in 1985 as follows:

Bacillus thuringiensis var. kurstaki (B.t.)

Futura; 2 x 20 BIU, at 1.4 l/ha
Futura; 2 x 30 BIU, at 2.1 l/ha
Thuricide 48LV; 2 x 30 BIU, at 2.36 l/ha
Thuricide 64B; 2 x 30 BIU, at 1.78 l/ha

Dimilin (diflubenzuron)

1 x 30 g ai/ha, at 2.0 l/ha
1 x 35 g ai/ha, at 4.7 l/ha
1 x 70 g ai/ha, at 4.7 l/ha
2 x 70 g ai/ha, at 4.7 l/ha

Sumithion (fenitrothion)

Technical (waterbase); 2 x 210 g ai/ha, at 1.5 l/ha
Flowable 20F; 2 x 140 g ai/ha, at 1.5 l/ha
Flowable 20F; 2 x 210 g ai/ha, at 1.5 l/ha

Matacil 180F (aminocarb)

2 x 90 g ai/ha, at 1.5 l/ha
2 x 135 g ai/ha, at 1.5 l/ha
2 x 180 g ai/ha, at 1.5 l/ha

Sprays were applied under optimal weather conditions, except the first application of Futura® at 30 BIU when wind gusts above 5 kph occurred. However, good spray deposits were recorded on Kromekote® cards placed along a 3 m to 5 m transect for all spray applications. Spray deposits on foliage were sampled for B.t., Sumithion and Matacil treatments and acceptable amounts of deposits were recorded for all except low deposits for the first applications of Futura at 30 BIU/ha and Sumithion Technical. Population reduction was computed using Abbott's formula (1925).

Futura at 2 x 20 BIU/ha did not reduce populations of late instar larvae nor pupae, but Futura at 2 x 30 BIU/ha reduced pupal numbers by 84% but larval numbers only by 10%. Thuricide 48LV® at 2 x 30 BIU/ha reduced larval population by 34% and pupal numbers by 82%. Thuricide 64B® at 2 x 30 BIU/ha gave 100% control of both late-instar larval and pupal populations.

Dimilin at 30 g and 35 g ai/ha provided no reduction of larval population and little reduction of pupal population. Applied once at 70 g ai/ha Dimilin provided no reduction of larval numbers, but gave 92% reduction of pupal numbers. Dimilin applied twice at 70 g ai/ha provided 100% reduction of both larval and pupal numbers.

Sumithion Technical provided 63% reduction of larval populations and 74% reduction of pupal populations, in spite of its low foliar deposit. The efficacy of Sumithion Technical may have been reduced because the emulsifier was inadvertently omitted in the first application. The new flowable formulation of Sumithion provided little or no population reduction of larvae or pupae in spite of excellent deposit on the foliage. The reasons for this are not readily apparent.

All dosages of Matacil gave little or no reduction of larval or pupal populations.

Based on our results Thuricide 64B at 30 BIU/ha and Dimilin at 70 g ai/ha are potential practical alternatives to fenitrothion for use against the hemlock looper for large-scale operational use, but foliage protection still needs to be demonstrated.

ÉPANDAGES AÉRIENS EXPÉRIMENTAUX DE PRÉPARATIONS DE BACILLUS
THURINGIENSIS, DE DIMILIN, DE SUMITHION, ET DE MATACIL CONTRE

L'ARPEUTEUSE DE LA PRUCHE (LAMBDA FISCCELLARIA FISCCELLARIA)

À TERRE-NEUVE EN 1985

RÉSUMÉ

Diverses préparations de Bacillus thuringiensis var. kurstaki (B.t.), de Dimilin®, de Sumithion® et de Matacil® ont été épandues par voie aérienne pour en contrôler l'efficacité contre l'arpeuteuse de la pruche (Lambdina fiscellaria fiscellaria (Guen.)) (Geometridae) à Terre-Neuve en 1985. Les préparations examinées sont les suivantes:

Bacillus thuringiensis var. kurstaki (B.t.)

Futura; 2 fois 20×10^9 UI, à 1,4 l/ha
Futura; 2 fois 30×10^9 UI, à 2,36 l/ha
Thuricide 48LV; 2 fois 30×10^9 UI, à 2,36 l/ha
Thuricide 64B; 2 fois 30×10^9 UI, à 1,78 l/ha

Dimilin (Diﬂubenzuron)

1 fois 30 g/ha d'ingrédient actif, à 2,0 l/ha
1 fois 35 g/ha d'ingrédient actif, à 4,7 l/ha
1 fois 70 g/ha d'ingrédient actif, à 4,7 l/ha
2 fois 70 g/ha d'ingrédient actif, à 4,7 l/ha

Sumithion (fénitrothion)

"Technical" (base aqueuse): 2 fois 210 g/ha d'ingrédient
actif, à 1,5 l/ha
"Flowable" 20F: 2 fois 140 g/ha d'ingrédient actif,
à 1,5 l/ha
"Flowable" 20F: 2 fois 210 g/ha d'ingrédient actif,
à 1,5 l/ha

Matacil 180F (aminocarbe)

2 fois 90 g/ha d'ingrédient actif, à 1,5 l/ha
2 fois 135 g/ha d'ingrédient actif, à 1,5 l/ha
2 fois 180 g/ha d'ingrédient actif, à 1,5 l/ha

Les liquides de pulvérisation ont été appliqués dans les meilleures conditions atmosphériques possibles. Toutefois, lors de la première application de Futura® à raison de 30 milliards d'unités internationales (MUI) par hectare, des rafales de vent supérieures à 5 km/h se sont produites. Cependant, de bons dépôts ont été relevés sur des cartes Kromekote® placées le long d'un transect de 3 à 5 m pour tous les arrosages. Les dépôts sur le feuillage ont été échantillonnés dans le cas des traitements au B.t., au Sumithion et au Matacil, et, dans tous les cas, les quantités de dépôts étaient acceptables, sauf après la première application de Futura à raison de 30 MUI/ha et de Sumithion Technical. La diminution de la population a été calculée à l'aide de la formule d'Abbott (1925).

Deux applications de 20 MUI de Futura par hectare n'ont pas eu d'effet sur les populations de larves du dernier stade et de pupes; toutefois, deux arrosages à un dosage de 30 MUI/ha ont réduit de 84% le

nombre de pupes, mais seulement de 10% la population de larves. Deux pulvérisations de Thuricide 48LV® à raison de 30 MUI/ha ont réduit de 34% la population de larves, et de 62% le nombre de pupes. Deux applications de 30 MUI de Thuricide 64B® par hectare ont permis d'éliminer toutes les larves du dernier stade, et il en a été de même pour les pupes.

Le Dimilin, pulvérisé à raison de 30 g et de 35 g d'ingrédient actif par hectare, n'a eu aucun effet sur la population de larves et a été peu efficace pour réduire le nombre de pupes. Un dosage de 70 g/ha n'a donné aucun résultat dans le cas de larves, mais 92% des pupes ont été détruites. Pulvérisé deux fois à raison de 70 g d'ingrédient actif par hectare, le Dimilin a éliminé la totalité des larves et des pupes.

En dépit de son faible taux de dépôt, le Sumithion Technical a réduit de 63% la population de larves, et de 74% le nombre de pupes. Il est possible que l'efficacité du Sumithion Technical ait été réduite parce qu'on a omis par inadvertance d'ajouter de l'émulsifiant lors de la première application. La nouvelle préparation, le Sumithion Flowable, s'est avérée peu efficace, sinon pas du tout, contre les larves ou les pupes, en dépit des excellents dépôts relevés sur le feuillage. Cet échec est difficile à expliquer.

Tous les dosages de Matacil n'ont pratiquement pas donné de résultats, que ce soit dans le cas des larves ou des pupes.

D'après les essais que nous avons effectués avec le Thuricide 64B (30 MUI/ha) et le Dimilin (70 g d'ingrédient actif par hectare), ces produits pourraient remplacer le fénitrothion et être utilisés sur une grande échelle pour lutter contre l'arpenteuse de la pruche, mais la protection d'arbres besion d'être démontrée.

THE EFFECTIVENESS OF BACILLUS THURINGIENSIS, DIMILIN, SUMITHION AND
MATACIL AGAINST THE HEMLOCK LOOPER, LAMBDA FISCELLARIA FISCELLARIA,
IN NEWFOUNDLAND IN 1985

by

A.G. Raske¹, A. Retnakaran², R.J. West¹, J. Hudak¹ and K.P. Lim¹

INTRODUCTION

The hemlock looper, Lambdina fiscellaria fiscellaria Guen., is a very destructive defoliator of balsam fir, Abies balsamea (L.) Mill., in Newfoundland. Its life history has been described by Watson (1934), de Gryse and Schedl (1934), Carroll (1956), and Otvos et al. (1971). The hemlock looper overwinters as an egg, and in Newfoundland peak larval hatch occurs in late June (Otvos et al. 1971). Eggs laid in exposed sites hatch first, whereas those laid beneath the canopy or other shaded areas hatch last (Carroll 1956). The first two larval instars feed mostly on the new foliage generally stripping one side of a needle leaving the remainder to shrivel and die (Fig. 1). Third and fourth instar larvae feed wastefully on old foliage, usually feeding at the base or side of a needle, allowing the remainder to die and drop (Fig. 2). Throughout the larval period this insect feeds in the open and is therefore readily exposed to aerially applied insecticides. Larvae produce abundant silken threads which tend to catch wasted red foliage (Fig. 3) giving severely defoliated trees a characteristic dark red-brown appearance. Feeding is generally completed by late July or early August. Larvae then crawl down to pupate on the bole entwining themselves in or under various lichen species, in the duff, or on adjacent vegetation (Fig. 4).

Adults emerge in early to mid-September, mate and oviposit on host trees and on a variety of substrates such as lichens, in moss on the forest floor and under the bark of mature birch (Carroll 1956, Otvos et al. 1971, Otvos and Bryant 1972, Jobin and Desaulniers 1981). On Anticosti Island in 1972, 98% of the eggs were laid on balsam fir and 2% on old logs, stumps, ground, etc. Of those eggs laid on host trees 99% were laid among lichens in the crown: 52% on the stem, 30% on the

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branches and 17% on twigs; 1% of the eggs were laid among lichens on the trunk below the crown (Jobin and Desaulniers 1981). Otvos et al. (1971) reported that weather during the oviposition period influences where eggs are laid. During windy, cool, and moist periods moss, stumps and undergrowth are more often selected, but during calm, warm periods the upper bole and crown of the host are more frequently utilized. Moths are active till late October.

The hemlock looper has reached outbreak levels periodically in Newfoundland since the turn of the century (Carroll 1956, Otvos et al. 1979). Tree mortality resulted from several early outbreaks, however, the last outbreak, 1967 to 1971, was the largest and an estimated 12 000 000 m³ of merchantable wood was killed (Otvos et al. 1979).

Several types of insecticides have been tested for the control of looper populations. Application of arsenic compounds in the 1920s generally reduced larval numbers by 90% to 100% where good coverage was achieved (Prebble 1975). Application of DDT in Ontario in the 1950s also gave good control (Harnden and Bricault 1975).

In 1968 in Newfoundland, 175 000 ha were sprayed to control the hemlock looper. Most of the areas were treated with an oil-based formulation of Sumithion® (fenitrothion) but some areas in western Newfoundland were sprayed with Dimecron® (phosphamidon) (Holmes and Brennan 1968). Dimecron gave nearly 100% larval reduction after two applications of 140 g ai/ha, and Sumithion reduced larval numbers by 87% with two applications of 140 g ai/ha and by 62% with one application of 280 g ai/ha. However, the 280 g ai/ha spray was applied later in the season and the larger larvae may have been more resistant to the insecticide (Otvos et al. 1971). Insecticide treatment did not alter the sex ratio of survivors but may have reduced the fecundity of surviving females (Otvos and Carter 1970).

In 1969 in Newfoundland 42 000 ha and 830 000 ha were treated with Dimecron and Sumithion, respectively (Holmes 1970, Otvos and Warren 1975). Sumithion reduced larval numbers by an average of 94%, and 80% larval reduction was achieved with phosphamidon (Otvos et al. 1971).

On Anticosti Island in 1972 a total of 167 000 ha received two applications of 140 g ai/ha each of a water-based formulation of Sumithion (Jobin 1975). Percent larval reduction varied from 70% to 93% in five different sectors and averaged about 80% for the whole Island (Jobin and Desaulniers 1981). In 1973 a total of 42 000 ha were treated with Sumithion or Dimecron in the first application, with most areas receiving Sumithion. Sumithion only was used for the second application (Jobin 1975). Larval reductions in sprayed areas averaged 96.6% to 97.5%, but fungal diseases caused 94% larval mortality in the control plots (Jobin and Desaulniers 1981).

In 1973 on Anticosti Island, the juvenile hormone Altosid® was sprayed experimentally against the looper, and its efficacy evaluated by pupal-trap and moth counts. Pupal trap counts in sprayed areas were 3% to 20% of counts in control areas and the number of male moths was reduced by a factor of 5 to 8. The number of eggs in treated plots was about half of those in control plots (Retn/karan et al. 1975).

In Newfoundland populations of hemlock looper have progressively increased since 1981 with a concomitant decline in numbers of the spruce budworm, Choristoneura fumiferana (Clem.). In 1983 two isolated outbreaks of the hemlock looper were recorded; one of 200 ha in Bay d'Espoir and a larger outbreak of 9 000 ha on the Avalon Peninsula (Fig. 5) (Clarke and Carew 1984). In 1984 areas of moderate and severe defoliation caused by the looper increased sharply to 95 000 ha (Clarke and Carew 1985) with several new infestations appearing across the Island (Fig. 6). An Island-wide egg survey in 1984 led to a forecast of 273 000 ha of moderate and severe defoliation and 437 000 ha of light defoliation for 1985 (Clarke and Carew 1985) (Fig. 7). Based on this information, the province of Newfoundland considered control options to lessen impending damage by the threatening looper outbreak. Only three commercial formulations of fenitrothion, including Sumithion, are currently registered for use in Canada against the hemlock looper. It was decided to test a carbamate, Matacil® (aminocarb); an organo-phosphate, a flowable waterbased formulation of Sumithion 20F (fenitrothion); two formulations of Bacillus thuringiensis var. kurstaki (B.t.) and an insect growth regulator, Dimilin® (diflubenzuron) for use against the hemlock looper. All these insecticides are currently registered for forestry use against certain insect pests in North America, but need to be field-tested in aerial spray trials to obtain the efficacy data required for their registration for use against the hemlock looper.

The results of experimental aerial sprays of various dosages or formulations of Matacil, Sumithion, B.t., and Dimilin applied to early and mid-instar hemlock looper larvae near Bay d'Espoir in 1985 are presented in this report.

MATERIALS AND METHODS

Site, Experimental Design and Block Establishment

We tested the materials near the inlet of Bay d'Espoir, Newfoundland, an area bounded by 55°35'-55°40'W longitude and 47°55'-48°10'N latitude (Fig. 8). The results of egg surveys in May 1985 were used to

locate 18 treatment and 6 control blocks within this general area. The terrain was relatively flat and the forests were comprised mainly of balsam fir. Plots 5, 6 and 18 contained white birch, Betula papyrifera Marsh., and plots 15 and 17 contained patches of black spruce, Picea mariana (Mill.) B.S.P. Other tree species were rare. The site is classified as "good" in the provincial inventory system of classification (Delaney and Osmond 1975).

Trees on most plots were 4 m to 5 m in height but ranged up to 10 m in height on some plots. We tried to locate blocks in stands thinned in the mid-1970s. Trees in these stands tended to have full crowns, and their spacing allowed for good spray coverage. For logistical reasons we located plots near existing roads when possible.

Each treatment block was 15 ha in area and measured 300 m by 500 m (Fig. 9). The block was bisected at right angles to the line of flight by a 3 m to 5 m wide cleared transect which extended 45 m beyond the boundary on each side. Overhanging branches of border trees were removed to create discrete canopy openings to the ground. These openings enabled the ground crew to guide the spray aircraft with a helium-filled balloon, and allowed relatively unrestricted movement of spray droplets to Kromekote® cards placed on this transect.

Trees to be sampled for looper numbers and for foliage deposits, were chosen at or near the moving-balloon line (Fig. 9). Twenty trees were tagged within 90 m of each side of the mid point of this line for a total of 40 sample trees per block (Fig. 9). The outer 60 m of each side of the plot was left without sample trees so that if drifting occurred, it would not reduce the number of usable sample trees (Fig. 9).

Six areas were designated as control plots (Fig. 8). These were not surveyed in the rectangular configuration, but 40 trees in nearly straight lines were tagged for repeated sampling.

Aircraft Parameters

All treatments were applied by Piper Pawnee aircraft, fitted with six AU 5000 Micronair atomizers (supplied by Micronair, Aerial Ltd., Sandown, Isle of Wight, England) (Figs. 10, 11). The rate of flow was calibrated to deliver the desired volume in a swath width of 30 m. The aircraft flew at 160 km/h and about 20 m above the general tree canopy.

B.t. and Dimilin were sprayed first followed by Matacil and Sumithion. Lower concentrations of material were sprayed before higher concentrations. Tanks in the airplane, booms and micronairs were washed thoroughly between sprays.

Communication

Our base of operations was the Management Unit Office, Department of Forest Resources and Lands, at Head of the Bay, Bay d'Espoir, located about 5 km from the nearest spray block. A radio-telephone network maintained contact during spray operations between the airstrip, base control station, the spray aircraft and mobile ground stations in the experimental plots.

Insect Numbers Assessment

Insect sampling was done either by: 1) counting the larvae on mid-crown branches collected from plots with a high population of loopers or 2) counting larvae dislodged onto white sheets from branches by beating trees in plots with low population levels. The latter method sampled more area of foliage and consequently resulted in higher larval counts. In plots with pre-spray population levels of > 2.5 looper larvae per branch, one mid-crown branch was collected from each of the 40 sample trees and the larvae counted. In plots with population levels of ≤ 2.5 larvae per branch, "beating samples" were taken (Fig. 12). This consisted of striking the branches of one side of ten trees with downward strokes with a 3 m long pole, and collecting the larvae that had fallen on a 2.3 x 3 m cloth placed beneath each tree. Sampled trees were marked to prevent resampling. Looper development was monitored in four plots to decide when to spray.

Pre-spray larval counts were taken within 24 hours prior to spraying with Matacil or Sumithion and within 48 hours of spraying with B.t. and Dimilin. Mid-spray larval sampling was done within 72 hours after the first spray for the chemical treatments and within 72 hours before the second treatments for B.t. and Dimilin. Post-spray sampling was done within a week after the final spray for all treatments. Control plots were sampled weekly during spray periods.

The number of looper larvae surviving to pupation was determined with the use of burlap traps (Figs. 14, 15) (Otvos 1974). Pieces of burlap 90 cm long were folded, wrapped around the bole at breast height, and fastened with staples on each of the 40 sample trees (Fig. 15). Traps were placed in late July, just prior to first pupation, and collected in late August when larvae no longer occurred in the crowns. The "number of pupae" used in this report is the total number of looper larvae that entered and were caught in the trap.

At each sample date and for each plot up to 100 larvae (or pupae) were retained for rearing to determine percent parasitism and disease. Larvae were reared individually in 34 ml plastic containers

and fed fir foliage every four or five days. Dead larvae and pupae were examined to determine cause of death.

Spray Application

Two applications were planned for most treatments because the hatching period is prolonged. The second spray, scheduled five days after the first, was intended for those larvae that hatched after the first spray. The first sprays of B.t. and Dimilin were applied July 3 and 5, when 75% of the larvae were in the second instar, 17% in the first and 8% in the third (Table 1). The first application of Matacil and Sumithion was sprayed between July 6 and 12 when 50% to 80% were in the second instar, 3% to 5% in the first and the remainder in the third instar (Table 1). The prolonged hatching period reported for earlier years (Carroll 1956) did not occur in the study area in 1985. After the initial burst of hatching, June 23 to 27, the proportion of first instar larvae dropped to 5% or less between July 6 and 13 (Table 1). The delayed hatch was of much smaller proportion than expected, but agrees with a study of the distribution of eggs sampled in fall of 1984 (Dobesberger,¹ unpublished data) when about 5% of the eggs were laid in cool forest habitats.

Unfavourable weather prevented applying the second spray five days after the first. Second applications were made between July 19 and July 22. At that time 65% of the larvae were in the third instar with about equal proportions in the second and fourth instars (Table 1).

Insecticide Formulation and Tank Mixes

All insecticides were applied as aqueous formulations adding only the dye, Erio Acid Red XB 400², as a marker (Table 2). The emulsifier Atlox 190, was inadvertently omitted in the formulation of the first application of Sumithion Technical and the Matacil at 180 g ai/ha. This was important because samples of spray deposit on foliage were taken only after the first application of these insecticides.

Meteorological Monitoring

Weather conditions during the spray were monitored at the base of operations, and included wind speed and direction, temperature at 2 m and at 10 m above ground. The latter was used to determine the temperature gradient: inversion -- temperature at ground level < aerial temperature; neutral -- ground temperature = aerial temperature; and lapsed conditions -- ground temperature > aerial temperature. A Heathkit

¹E. Dobesberger, Can. For. Serv., Newfoundland Forestry Centre, St. John's, Nfld.

²Supplied by Keystone Aniline Co., Chicago, Ill.

weather computer model I.D. 4001 (Fig. 16) was connected to sensors measuring these parameters. The computer's digital displays were manually recorded at 5-minute intervals beginning one hour before the spray and continuing for 15 minutes after. Relative humidity was measured with a portable psychrometer. Rainfall at the base station was recorded daily at 1300 h and general weather conditions at the plots were noted during the spray periods.

Spraying conditions were judged "good" for all applications except "fair" for the first application of Futura® at 30 BIU/ha (Plot 6) when the combination of wind (gusts up to 12 km) and a lapsed temperature condition provided less than ideal conditions (Table 3).

Spray Deposit Assessment

Spray deposit at ground level was monitored with units comprised of a 10 x 10 cm Kromekote card and two 5.0 x 7.5 cm glass plates (Fig. 17) as described by Randall (1980). Ground units were placed in the treatment blocks less than 30 minutes before and retrieved 30 to 60 minutes after treatment. Units were placed on stands about 30 cm above the ground, at 15 m intervals along the transect and extending 45 m beyond each plot boundary. Nearby vegetation was removed before placing the units to avoid overhead obstructions.

Most Kromekote cards were sent to the National Aeronautical Establishment, Ottawa, Ontario where they were analyzed by a Flying Spot Scanner (Drummond 1980). Other cards were analyzed by A. Sundaram, CFS, FPMI, Sault Ste. Marie, Ont. Droplet density and size, Number Median Diameter (NMD) and Volume Median Diameter (VMD) were determined. Droplet NMD is the droplet diameter that halves the number of droplets: half the droplets are smaller and half are larger. Droplet VMD is the droplet diameter that halves the droplet volume: half the droplets have volumes larger than the VMD and half the droplets have volumes smaller.

The spray deposit on the glass plates was used to estimate the volume that reached the ground. The material on the glass plate was washed off with methanol and colorimetrically measured for dye content in a Bausch and Lomb Spectronic 100 Spectrophotometer.

Spray deposit was also determined from foliage samples collected after both applications of the four B.t. formulations and after the first application of the chemical formulations.

For the B.t. applications, foliage samples were collected within one hour after treatment and packaged at the spray site for deposit assessment. Samples consisted of one mid-crown branch, unobstructed from above, collected from 16 of the 40 sample trees. Eight current year (1985) shoots were removed from each branch with forceps and

their bases individually wrapped in moistened tissue paper and then in tin foil. Wrapped shoots were placed separately in small paper bags, packed in styrofoam coolers and flown to the Research and Productivity Council, Fredericton, N.B. for analysis. Droplets on both sides of ten needles, randomly selected from each shoot were counted, and their diameters measured with a microscope.

For the chemical treatments, foliage samples were collected from one tree every 30 m along the cleared transect for a total of 11 trees per plot. Each sample consisted of one mid-crown branch, unobstructed from above, cut from a tree near a ground unit. Three current-year shoots (1985) and three previous years' shoots from near the branch tip were removed and placed into a plastic bag. Rubber gloves were worn by workers to avoid contamination of samples. Both the ground unit and the foliage samples were collected 30 to 60 minutes after the spray and kept at -10° to -20°C till shipment by air to the Forest Pest Management Institute (FPMI) for processing. Foliage samples were pooled before analysis to obtain measurable quantities of the active ingredients.

Foliage sampled for deposit analysis was chopped, divided into aliquots and the deposit extracted in methanol. The extracts were filtered to remove suspended particles, flash-evaporated to dryness, and the residues placed in a known volume of ethyl acetate. The amount of active ingredient (ai) in the residues was then determined by gas-liquid chromatography, and expressed in g ai/ha.

Spray Effects Assessment

The percent population reductions in the treatment blocks were corrected for natural mortality with Abbott's (1925) formula:

$$\% \text{ Population reduction} = \left[1 - \frac{\text{Post-spray pop. in treatment}}{\text{Pre-spray pop. in treatment}} \times \frac{\text{Pre-spray pop. in control}}{\text{Post-spray pop. in control}} \right] \times 100$$

Treatment plots were matched with control plots with a similar pre-spray population to determine the efficacy of treatment (Fleming and Retnakaran 1985).

Post-spray larval counts included diseased and parasitized larvae which died before pupation. This mortality might affect population reduction results, therefore, the proportion of larvae killed by

natural causes was determined and the pupal population reductions due to treatment adjusted as follows:

$$\text{Adjusted reduction} = \frac{\text{Unadjusted pupal reduction}}{100 - (\% \text{ diseased and } \% \text{ parasitized})} \times 100$$

In plots with low population levels additional branches were collected during post-spray sampling to determine the proportion of death by disease and parasitism. In plots with high population levels, the post-spray branch sample was used to determine the proportion of death by these natural causes.

Defoliation was assessed from the ground on August 13-14 and from the air on August 15. For the ground assessment 40 previously unsampled trees in each plot were classed into one of six defoliation percent categories as follows: 0, 1-25, 26-50, 51-75, 76-99 and 100.

Aerial assessments of defoliation for each plot were made by an experienced observer in a helicopter at an altitude of about 150 m above tree top and grouped into damage categories of nil, light (1-25%), moderate (26-75%) and severe (76-100%).

RESULTS AND DISCUSSION

Mixing

The formulations of all pesticides mixed well with water and dye and no difficulties were encountered in mixing nor in loading the plane.

Spraying

For the first treatment, only 4 of the 14 plots were sprayed in the morning - Futura at 20 BIU/ha and 30 BIU/ha, and Dimilin at 35 and 70 g ai/ha. For the second treatment 4 of 11 plots were sprayed in the morning - Matacil at 135 and 180 g ai/ha and Sumithion Technical at 210 g ai/ha and Sumithion 20F at 140 g ai/ha. All other sprays were applied in the evening.

Weather at the time of spray was ideal or nearly ideal for all 25 applications except during the first application of Futura at 30 BIU/ha when the weather data recorded at the base of operations showed a lapse of -1° to -2°C with winds occasionally gusting up to 12 km/h (Table 3). However, winds at the plot 12 km to the north of the weather station were probably less.

A rain-free period of at least 24 hours after the spray application was desirable to enable the material to dry onto the foliage and persist for a period to be effective. Two treatments, the first application of Sumithion and Matacil at 180 g ai/ha, were sprayed in the evening and rain fell about 20 hours after the spray (Table 3, Fig. 18). The rain probably had no measurable effect on these two treatments. Very heavy morning rains (58.5 mm) preceded three evening treatments of B.t. However, the foliage was dry when spraying started at 2000 to 2100 h. These treatments also received a very light rain (.5-1 mm) at 0330 h the next morning (Table 3). Additional rain fell from 1100 to 1400 h and again at 1800 to 2000 h. Total accumulation of these three rain periods was 4.2 mm.

Spray Deposit - Forest Floor

Kromekote Cards

Spray droplet density on Kromekote cards and droplet diameter spectra differed little between first and second application for all formulations. Therefore averages of the two applications are presented except where Atlox 190 was omitted in one of the applications (Table 4).

For the B.t. applications, droplet density on cards was not correlated with rate of application (Table 4). Droplet density on the cards was decidedly lower at $2.7/\text{cm}^2$ for Thuricide 48LV[®] than for the other three at 4.2 to $5.1/\text{cm}^2$, though it was sprayed at the highest rate of 2.36 l/ha. Droplet diameter spectra did not differ appreciably between the four treatments, although Thuricide 48LV had a slightly higher concentration of large droplets. These differences in droplet diameter spectra are considered insufficient to affect efficacy.

For the Dimilin treatments droplet density varied directly with rate of application (Table 4), with droplet density at the application rate of 2.0 l/ha about half that of the sprays applied at 4.7 l/ha. The range of droplet size was also reduced for the low volume spray, with maximum diameter of 182 μ versus 320 μ m for the greater rate of application. Also the proportion of fine droplets was greater for the low-volume application rate, as evidenced by the small NMD of 26 μ m. However, the VMD did not differ appreciably among the three types of Dimilin treatments. Differences in spray deposit characteristics recorded for the Dimilin treatments were unlikely to affect efficacy appreciably.

Differences in deposit of Sumithion Technical with and without Atlox 190 was confined to droplet density. With Atlox, droplet density at $7.3/\text{cm}^2$ was almost double that without Atlox at $4.3/\text{cm}^2$.

[Similar reductions of spray deposit also occurred on the foliage (Table 6)]. The formulation without the Atlox should have produced more droplets of larger diameter, but this did not occur.

The droplet spectra of the two concentrations of the Sumithion 20F formulations differed markedly from each other, though applied at the same rate of 1.5 l/ha (Table 4). The higher concentration reached the ground in fewer but larger droplets. The reason for these differences are not known, but are thought insufficient to affect efficacy results.

The same trend of fewer but larger droplets with increasing concentration of active ingredient that occurred for Sumithion 20F also occurred with Matacil (Table 4). The reason for this is not known. Differences in droplet size spectra between the Matacil formulation with and without Atlox did not occur. The difference between droplet density of 4.3/cm² without Atlox and 6.2/cm² with Atlox was small and was thought unlikely to affect efficacy of the insecticide appreciably.

Graphic presentations of the frequency distributions of droplet number and droplet volume by droplet-diameter size classes from the Kromekote cards have been appended (Appendix I).

Droplet density on the 21 Kromekote cards placed along the transect varied considerably about the means (Table 4), but in general spray coverage ranged from "acceptable" to "very good" (Appendix II). Drift along the boundary edges, when it occurred, did not extend beyond the 60 m buffer zone and therefore did not affect the trees sampled for population reductions. A few cards were without spray deposit and this may have been caused by a "shadowing" effect of nearby trees.

Only two spray coverage profiles were not in the "acceptable" category; the first application of each of the two chemical treatments without the emulsifier (Appendix II). Here the spray coverage was low for a sizeable portion of the plot. However, spray cover was excellent for the second application of both treatments. The effect of the lack of Atlox was small.

Glass Plates

Attempts to analyze spray deposits from the glass plates met with many problems. Deposits of B.t. sprays coagulated in the methanol wash. Therefore the dye was not released and could not be colorimetrically measured. The dye could not be detected in the plate washes of all Matacil applications, and also for some applications of Sumithion. Other applications of Sumithion gave plate washes with detectable dyes, but the relationship between concentration and absorption was not linear,

possibly because of interference of the formulation. The light-absorbing characteristic of colored material in the formulations may have caused a pH problem.

Analysis of glass plate data of the Dimilin sprays was consistent with data obtained from Kromekote cards (A. Sundaram *et al.* 1987). The dye was readily soluble, absorbed light, and a good linear relationship was observed between concentration and absorption. Dimilin sprayed at 2.0 l/ha gave estimates of ground deposits of 0.67 l/ha; i.e. one-third of the spray reached the ground. Four applications at 4.7 l/ha gave estimates of ground deposits of 0.58 l/ha, 2.28 l/ha, 2.36 l/ha and 3.37 l/ha. The low value of 0.58 l/ha (Plot 16, second application of 70 g ai/ha) was inconsistent with the droplet density data from the Kromekote cards (Table 4). At least half of the spray reached the ground in three out of four applications of Dimilin sprayed at 4.7 l/ha.

Spray Deposit - Foliage

West *et al.* (1987) have published results of spray deposits which are here summarized. Deposit of B.t. on the current year's foliage ranged in droplet diameter from near zero to 200 μ m for first and second applications, with nearly half the droplets 26 μ m to 50 μ m in diameter (Fig. 19). Droplet diameters of 1 to 75 μ m comprised at least 90% of the droplets on the foliage for all treatments. Range in droplet size was essentially the same for the second application as for the first. The average number of droplets per needle, was decidedly lower for the first application of Futura at 30 BIU at .08/needle than for other treatments which ranged from 0.34 to 1.34/needle (Table 5). This lower deposit of .08/needle may have been caused by the unexpected wind gusts and marginal lapse conditions during the spray (Table 3).

Differences in droplet density of spray deposits on foliage (Table 5) and Kromekote cards (Table 4) may have been caused by differences in the surface properties of cards and needles and physical characteristics of a flat surface on the ground and a comb-like arrangement of needles on a twig 3 m to 5 m above the ground.

Deposits of Sumithion and Matacil were measured on old and new foliage for the first application of each chemical. Deposit results have been published elsewhere (K.M.S. Sundaram *et al.* 1987) and a summary is presented in this report. Foliar deposit of Sumithion 20F varied with dosage (Table 6), and both were higher by a factor of about 10 compared to similar dosages of Matacil. Such high deposition was unexpected and has not been encountered before (K.M.S. Sundaram, personal communication). However, for the application of Sumithion Technical the amount of deposited material was decidedly low, possibly due to the lack of the emulsifier. For the Sumithion 20F formulations the greater concentration

of 210 g ai/ha came down in fewer but larger droplets (Table 4). However, more active ingredient was deposited at the greater concentration (Table 6). The deposits of Sumithion were greater on current than on one year old needles, but the reason for this is not known. Needle exposure should not have differed appreciably between the foliage of the two years but needle geometry, size, vertical orientation or needle-surface chemistry may have affected collection and retention of Sumithion.

The absolute amount of Matacil deposited on the ground and on the foliage increased with dosage but the increase was not always linear (Table 6). Ground deposits of the intermediate dose of 135 g ai/ha was below that expected for a linear relationship. The deposit on the current year's needles was always greater than that on the previous year's needles in spite of 1985 shoots being shorter and their needles not fully grown. Presumably the same factors were responsible as were for Sumithion. The lack of the emulsifier did not appear to affect the amount of deposit on the forest floor nor on the needles. The deposit on foliage was in general well correlated to data collected at ground level. Deposits of Matacil on the ground were roughly similar in droplet density and droplet-size spectra for all applications (Table 4). However, the concentration of Matacil in these droplets increased with increasing dosage (Table 6).

Population Reduction

Unfavourable weather delayed the second application. This may have affected the efficacy of the treatments. Larvae were given more time to feed and grow as well as recover from the effects of the first application. This increase in size may have provided increased resistance to the effects of the second application. In addition, feeding by larger larvae is more evenly distributed on all needles than that by smaller larvae which tend to feed on current-growth needles. Thus larger larvae probably received less insecticide by feeding on less exposed, inner foliage. Therefore, population reductions could have been higher had applications been made earlier.

B.t. treatments - Of the four B.t. treatments only Thuricide 64B® provided good control (Fig. 20, Table 7). Two applications of Futura at 20 BIU/ha provided no population reduction. Larval numbers remained high compared to all control plots, and pupal numbers were high, indicating excellent survival to that stage. Two applications of Futura at 30 BIU were applied to a rather low population. Larval populations were only reduced by 10% at the time of post-spray larval sampling, but percent reduction of pupae was high at 84% (Fig. 20). Applying Futura earlier, when larvae are in the first and second instar, may provide population reduction and also sufficient foliage protection to give satisfactory results in an operational spray program.

Thuricide 48LV was also applied to a rather low population of looper larvae (Table 7). Population reduction of post-spray larvae was only 34%, but pupal reduction was considerable at 82%. Like Futura at 30 BIU, earlier application of this formulation of B.t. might further reduce populations and provide sufficient foliage protection. Thuricide 64B applied at 2 x 30 BIU gave good control against a high initial population of looper larvae, reducing larval numbers by 100%. The added control provided by Thuricide 64B may be caused by its potency of 16 000 IU/mg compared to 12 000 IU/mg for Thuricide 48LV and Futura. Thuricide 64B is a good candidate for large-scale spray operations.

Dimilin treatments - Of the four Dimilin treatments only the dosage of 70 g ai/ha applied twice provided good control of looper populations (Table 7, Fig. 20). The two low dosages of 30 and 35 g ai/ha gave no reduction of larval numbers and little reduction of pupal numbers. One application of 70 g ai/ha did not reduce larval numbers but reduced pupal numbers by 92%. This latter dosage may provide acceptable control if applied early.

Two applications of 70 g ai/ha gave 100% control of larvae and pupae even when applied to an extremely high initial population level. During the post-spray larval sampling no larvae were detected in this plot, but larvae were reasonably abundant 50 m to 100 m outside of the sprayed plot. This dosage gave good population control and therefore would be a good candidate for large-scale control operations.

Sumithion treatments - The two dosages of the new formulation of Sumithion 20F tested provided little or no reduction of populations in both the larval and pupal stages in spite of good deposit (Table 7, Fig. 20). The late application of the insecticide may have been a contributing factor. Application of Sumithion Technical, the only formulation tested that is currently registered, reduced larval and pupal populations by about 70% (Table 7, Figure 24), when applied against a very high population level, however, population reductions did not occur by mid-spray. The emulsifier, Atlox 190, inadvertently omitted in the first application when larvae were small, may have caused the low deposit and therefore the low population reduction at mid-spray. The second application, with the emulsifier, may have been responsible for the larval and pupal reductions obtained.

Foliage deposit was very low for Sumithion Technical compared to the flowable formulation, yet the population reduction was decidedly higher. The reason for this is not clear. The population reduction of 70% is lower than the 80% to 94% reduction previously received in Newfoundland (Otvos et al. 1971) and the 70% to 93% received in Anticosti Island (Jobin and Desaulniers 1981). Application delay may in part account for the lower reduction in our study.

Based on these tests the flowable formulation of Sumithion does not appear to be a good candidate for control operations, even though excellent deposit of the active ingredient on the foliage was obtained. Because the emulsifier was inadvertently omitted in one of the formulations of Sumithion Technical, this chemical should be retested.

Matacil treatments - Preliminary laboratory experiments, done in winter of 1984-85 at FPPI, indicated that the looper was more resistant to Matacil than the spruce budworm. Lethal dosages (LD_{50}) for the looper were about four times greater than those for budworm larvae (B. Helson, personal communication). In our field tests two applications at the rate of 90 g ai/ha, the maximum registered dosage for the spruce budworm, did not reduce populations either at the larval or the pupal stage (Table 7, Fig. 20). The results remained unaltered when the dosage was increased to 135 g ai/ha. Even at double the maximum dosage required for the budworm, at 180 g ai/ha, only 30% to 36% reduction in population was achieved. Matacil does not appear to be a good candidate for hemlock looper control.

Fungal Diseases

Larvae that died of diseases were observed in the four plots with high populations - one plot each in Dimilin, Matacil and Sumithion treatments - and in one of the control plots (F) of the test area. Both lab and field data were in agreement as to the approximate frequency of fungal diseases in the plots. We incorporated a disease-correction factor to the population reduction calculation (Appendix III), but the "corrected" reduction figures did not differ appreciably from the uncorrected figures. Therefore the latter figure has been used in the population reduction estimates.

Foliage Protection

Before the weather-delayed applications were completed, the insect had developed into third and fourth instars. These stages caused a considerable amount of defoliation prior to spraying in plots with high population levels. Furthermore, heavy rains washed off the brown, damaged needles resulting in variable aerial estimates of defoliation. There was also poor correlation between insect numbers and degree of defoliation. Therefore, foliage protection data were inconclusive. A summary of the defoliation data is appended (Appendix IV).

CONCLUSIONS

Double applications of insecticides were made because a prolonged hatching period of hemlock looper larvae was expected. The second spray was intended for those larvae still unhatched at the time of the first spray. However, the prolonged hatching period, evident in past years, did not occur in the test area in 1985. Therefore, almost all larvae received two applications.

The only B.t. formulation that gave good larval reduction was Thuricide 64B applied at 30 BIU/ha. However, foliage protection was not achieved because the second application was delayed. The other B.t. formulations applied at the same dosage reduced only pupal numbers and gave no foliage protection. Poor spray deposit at the first application may have accounted for the low effectiveness of Futura at 2 x 30 BIU/ha. This treatment should be retested. Earlier applications of B.t. should also be tested for foliage protection.

A double application of Dimilin at 70 g ai/ha in 4.7 l/ha effectively controlled the looper numbers but provided no foliage protection in 1985. The large population reduction which occurred at this dosage in the treatment block contrasted sharply to the control block and to the adjacent untreated area. A single application of this dosage reduced only pupal numbers and it may not be an acceptable dosage for foliage protection unless applied earlier. Two early applications of 70 g ai/ha in the ultra-low volume of about 2.0 l/ha should be tested.

Water-based formulations of Sumithion provided only partial control at the dosages tested. Even the registered dosage of 2 x 210 g ai/ha was less effective than Thuricide 64B at 30 BIU/ha and Dimilin at 2 x 70 g ai/ha. Because the emulsifier, Atlox 190, was inadvertently omitted from the spray mix, this treatment should be retested. Earlier applications should also be tested for foliage protection.

Matacil was not effective against the looper even at 2 x 180 g ai/ha, which is twice the maximum dosage registered for spruce budworm control. This ineffectiveness of Matacil was in agreement with laboratory investigations.

Based on our results Thuricide 64B at 2 x 30 BIU/ha and Dimilin at 2 x 70 g ai/ha may be considered as potential practical alternatives to Fenitrothion against the hemlock looper but foliage protection still needs to be demonstrated. In addition, these two insecticides will have to be registered before their large-scale operational use.

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Table 1. Development of hemlock looper larvae near Bay d'Espoir, Newfoundland in 1985.

Date	% Instar				Total number in sample
	1st	2nd	3rd	4th	
June 27	98	2	0	0	622
July 1	12	88	0	0	206
July 3-5	17	75	8	0	3146
July 6	5	68	27	0	1985
July 9	4	78	18	0	3023
July 11	3	51	46	0	1119
July 13	5	58	37	0	1079
July 15, 16	1	29	67	3	1689
July 17, 18	1	18	65	16	1048
July 24, 25	1	9	34	56	1580
July 29, 30	0	0	41	59*	266*

*Pupae now abundant but not included.

Table 2. Formulations of insecticide tested against the hemlock looper in Newfoundland in 1985.

Name of concentrate	Rate of appli- cation (l/ha)	Area sprayed (ha)	Active ingred- ient (per ha)	Total volume applied (l)	Wt. or vol. of concen- trate in mix	% Erio acid red dye	Atlox 190 emulsifier (ml)	Diluent (water) (l)	No. of appli- cations
Futura	1.4	15	20 BIU	21.0	21.0 l	0.5	-	-	2
Futura	2.1	15	30 BIU	31.5	31.5 l	0.5	-	-	2
Thuricide 48LV	2.36	15	30 BIU	35.4	35.4 l	0.5	-	-	2
Thuricide 64B	1.78	15	30 BIU	26.7	26.7 l	0.5	-	-	2
Dimilin 25 wp*	2.0	15	30 g	30.0	4.2 kg	1.0	-	30.0	1
Dimilin 25 wp*	4.7	15	35 g	70.5	2.1 kg	1.0	-	70.5	1
Dimilin 25 wp*	4.7	15	70 g	70.5	4.2 kg	1.0	-	70.5	1
Dimilin 25 wp*	4.7	15	70 g	70.5	4.2 kg	1.0	-	70.5	2
Sumithion Tech.	1.5	15	210 g	22.5	2.5 l	1.0	340**	19.5	2
Sumithion 20F#	1.5	15	140 g	22.5	10.5 l	1.0	-	11.0	2
Sumithion 20F#	1.5	15	210 g	22.5	15.75 l	1.0	-	67.5	2
Matacil 180F	1.5	15	90 g	22.5	7.5 l	1.0	340	15.0	2
Matacil 180F	1.5	15	135 g	22.5	11.25 l	1.0	340	11.25	2
Matacil 180F	1.5	15	180 g	22.5	15.0 l	1.0	340**	7.5	2

* Wettable powder.

** Atlox 190 was inadvertently omitted in the mix of the first application only.

A flowable formulation.

Table 3. Application rates and weather data for treatments of Bacillus thuringiensis against the hemlock looper near Bay d'Espoir, Newfoundland in 1985.

	Plot 5		Plot 6		Plot 18		Plot 14	
	Futura		Futura		Thuricide 48LV		Thuricide 64B	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Rate (l/ha)	1.4	1.4	2.1	2.1	2.36	2.36	1.78	1.78
BIU/ha	20	20	30	30	30	30	30	30
Date applied	July 3	July 19	July 3	July 19	July 5	July 21	July 5	July 19
Time (h)	0610	2015	0715	2105	2015	1955	2100	2025
Temp °C (mean)	11.8	18.0	14.5	17.0	17.3	20.5	15.3	18.0
RH % (mean)	82.0	84.0	74.0	86.0	74.0	69.0	83.5	82.0
No. hrs. to next rain	24	7	24	7	42	36	42	7
Windspeed km/h (mean)	2.3	0	8.3	0.6	5.5	5.0	2.6	0.6
Windspeed km/h (range)	1-5	0	5-12	0.2	4.7	3-6	1-3	0-1
Wind direction	SW-W	W	SW-W	SW-W	SW-SSW	SW	WSW-SSW	SW-W
Air stability*	↔ to ↓	↓	↑	↓	↔ to ↑	↔ to ↑	↔ to ↑	↔ to ↓

* ↓ = inversion, ↑ = lapse, ↔ neutral (isothermic).

.../Cont'd.

Table 3 (cont'd.). Application rates and weather data for treatments of Dimilin® against the hemlock looper near Bay d'Espoir, Newfoundland in 1985.

	Plot 9		Plot 10		Plot 11		Plot 16	
	Application		Application		Application		Application	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Rate (l/ha)	4.7		4.7		2.0		4.7	4.7
Dose (g ai/ha)	35		70		30		70	70
Date applied	July 3		July 3		July 5		July 5	July 21
Time (h)	0543		0618		2030		2116	2000
Temp °C (mean)	10.5		12.5		16.0		14.5	20.0
RH % (mean)	84		82		76		86	70
No. hrs. to next rain	24		24		42		42	36
Windspeed km/h (mean)	2.1		3.0		3.6		3.0	3.5
Windspeed km/h (range)	1-4		2-4		3-5		1-6	1-6
Wind direction	ESE-SSE		SW-SSW		WSW-SW		SSW	SW-SSW
Air stability*	↓		↑ to ↔		↔ to ↑		↓	↔ to ↑

* ↓ = inversion, ↑ = lapse, ↔ neutral (isothermic).

.../Cont'd.

Table 3 (cont'd.). Application rates and weather data for treatments of Sumithion[®] against the hemlock looper near Bay d'Espoir, Newfoundland in 1985.

	Sumithion Technical		Sumithion 20F			
	Plot 17		Plot 12		Plot 13	
	1st	2nd	1st	2nd	1st	2nd
Rate (l/ha)	1.5	1.5	1.5	1.5	1.5	1.5
Dose (g ai/ha)	210	210	140	140	210	210
Date applied	July 6	July 22	July 10	July 22	July 12	July 21
Time (h)	2045	0720	2045	0605	2105	2040
Temp °C (mean)	18.0	10.5	17.5	7.0	14.0	19.3
RH % (mean)	72	88	85	88	88	72
No. hrs. to next rain	20	24	36	24	72+	36
Windspeed km/h (mean)	7.1	0.2	3.0	0	4.8	3.0
Windspeed km/h (range)	6-10	0-1	2-6	0	3-7	2-4
Wind direction	SW-SSW	SSW	SW-WSW	-	W	SW-WSW
Air stability*	↑ to ↔	↑	↑	↔ to ↑	↔ to ↑	↑

* ↑ = inversion, ↑ = lapse, ↔ neutral (isothermic).

1
2
3
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Table 3 (concl'd.). Application rates and weather data for treatments of Matacil 180P[®] against the hemlock looper near Bay d'Espoir, Newfoundland in 1985.

	Plot 7		Plot 8		Plot 15	
	1st	2nd	1st	2nd	1st	2nd
Rate (l/ha)	1.5	1.5	1.5	1.5	1.5	1.5
Dose (g ai/ha)	90	90	135	135	180	180
Date applied	July 10	July 21	July 12	July 22	July 6	July 22
Time (h)	2035	2050	2050	0550	2035	0710
Temp °C (mean)	17.5	19.0	15	7	18.0	10.4
pH % (mean)	85	74	88	88	72	88
No. hrs. to next rain	36	36	72+	24	20	24
Windspeed km/h (mean)	2.8	2.0	5.4	0	5.5	1.0
Windspeed km/h (range)	1-6	0-4	4-7	0	5-6	0-3
Wind direction	SW-WSW	SW-ESE	WSW-W	-	SW-SSW	S-SSW
Air stability*	†	†	↔ to †	↔	† to ↔	†

* † = inversion, † = lapse, ↔ neutral (isothermic).

Table 4. Spray deposit characteristics on Kromekote® cards placed 30 cm above the ground during aerial sprays against the hemlock looper in Newfoundland in 1985. Table contents are average of two applications on 21 cards per application.

Treatment	Dosage	Volume rate (l/ha)	Droplet density (per cm ²)	Droplet Diameter (µm)			
				Min.*	Max.	NMD**	VMD**
Futura	20 BIU	1.4	4.7	15	93	51	66
Futura	30 BIU	2.1	5.1	15	90	54	66
Thuricide 48LV	30 BIU	2.36	2.7	15	140	44	81
Thuricide 64B	30 BIU	1.78	4.2	15	103	46	63
Dimilin	30 g	2.0	5.6	8	182	26	150
Dimilin	35 g	4.7	10.1	8	320	60	174
Dimilin	70 g	4.7	9.9	8	312	43	145
Sumithion 20F	140 g	1.5	17.8	9	126	26	63
Sumithion 20F	210 g	1.5	7.2	9	215	84	128
Sumithion Tech. (without Atlox)	210 g	1.5	4.3	5	75	31	39
Sumithion Tech. (with Atlox)	210 g	1.5	7.3	5	90	27	43
Matacil 180F	90 g	1.5	7.3	5	69	11	42
Matacil 180F	135 g	1.5	8.6	5	90	17	56
Matacil 180F (without Atlox)	180 g	1.5	4.3	5	120	53	66
Matacil 180F (with Atlox)	180 g	1.5	6.2	5	110	50	63

* Detection limit of measuring technique.

** NMD = Number Median Diameter, VMD = Volume Median Diameter. See text in Spray Assessment for explanation.

Table 5. Number of droplets per needle on current-year balsam fir foliage after aerial application of Bacillus thuringiensis in Newfoundland in 1985 (n = 1080 needles/application).

Formulation	Dose (BIU/ha)	First Application	Second Application
Futura	20	0.38	0.34
Futura	30	0.08	0.53
Thuricide 48LV	30	0.33	1.34
Thuricide 64B	30	0.46	0.70

Table 6. Spray deposit on glass plates at the forest floor and on 1984 and 1985 needles 30 minutes after aerial application of Matacil[®] and Sumithion[®] in Newfoundland in 1985.

Treatment	Dosage (g ai/ha)	Average deposit on forest floor (g ai/ha)	Average % deposited	Average deposit on 1984 needles (ppm)	Average deposit on 1985 needles (ppm)
Sumithion 20F	210	37.8	18.0	7.72	12.54
Sumithion Tech.*	210	7.5	3.6	1.06	1.47
Matacil 180F	90	7.7	8.6	.55	.64
Matacil 180F	135	8.7	6.5	.80	1.07
Matacil 180F*	180	15.3	8.5	1.22	1.99

* The emulsifier Atlox 190 was inadvertently left out of the formulation.

Table 7. Results of aerial applications of insecticides used against the hemlock looper in Newfoundland in 1985.*

Treatment	Plot No.	No. applications and dosage (BIU or ai/ha)	Weather conditions at spray time	Total No. of Hemlock Looper in Samples**			% Population Reduction†	
				Pre-spray larvae	Post-spray larvae	Pupae	Post-spray larvae	Pupae
Futura Control	5 B	2 x 20	good	257	110	524	0	0
				222	46	184		
Futura Control	6 A	2 x 30	fair	80	25	20	10	84
				107	37	164		
Thuricide 48LV Control	18 A	2 x 30	good	66	15	18	34	82
				107	37	164		
Thuricide 64B Control	14 F	2 x 30	good	1225	4	2	100	100
				275	143	355		
Dimilin Control	11 B	1 x 30	good	270	221	369	0	0
				222	46	184		
Dimilin Control	9 A	1 x 35	good	100	109	73	0	52
				107	37	164		
Dimilin Control	10 B	1 x 70	good	161	44	11	0	92
				222	46	184		
Dimilin Control	16 F	2 x 70	good	1386	2	0	100	100
				275	143	355		

.../Cont'd.

Table 7 (Concl'd.)

Treatment	Plot No.	No. applications and dosage (BIU or ai/ha)	Weather conditions at spray time	Total No. of Hemlock Looper in Samples**			% Population Reduction†	
				Pre-spray larvae	Post-spray larvae	Pupae	Post-spray larvae	Pupae
Sumithion 20F Control	12 A	2 x 140	good	86 107	27 37	71 164	9	46
Sumithion 20F Control	13 C	2 x 210	good	142 278	131 67	424 274	0	0
Sumithion Tech. Control	17 F	2 x 210	fair	829 275	159 143	279 355	63	74
Matacil 180F Control	7 A	2 x 90	good	48 107	52 37	329 164	0	0
Matacil 180F Control	8 A	2 x 135	good	54 107	33 37	205 164	0	0
Matacil 180F Control	15 F	2 x 180	fair	204 275	68 143	184 355	36	30

* See text for discussion of defoliation in treatment and control plots.

** Larvae either total of 40 branches or beating samples of 10 trees, pupae total of 40 burlap traps.

† Calculated with Abbott's (1925) formula.

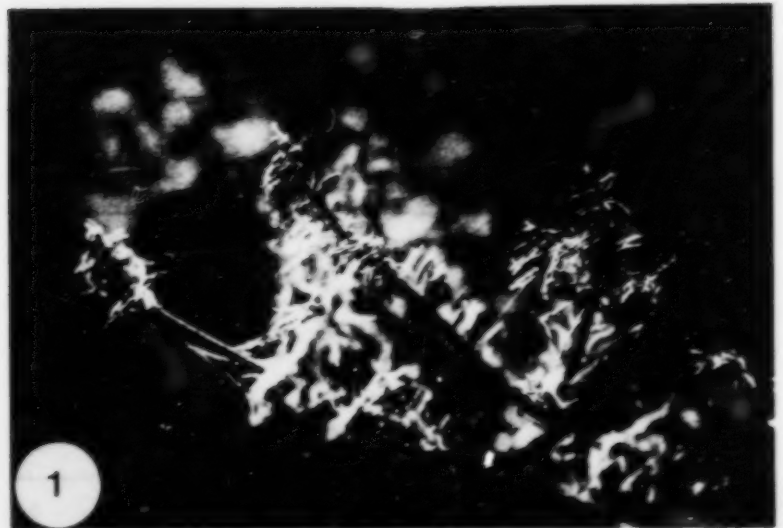


Figure 1. Defoliation by early instar hemlock looper larvae.

Figure 2. Defoliation by late instar hemlock looper larvae.



Figure 3. Severe defoliation of balsam fir by the hemlock looper with strands of red foliage in webbing.

Figure 4. Pupa of the hemlock looper.



Figure 5. Areas of hemlock looper defoliation in Newfoundland in 1983.

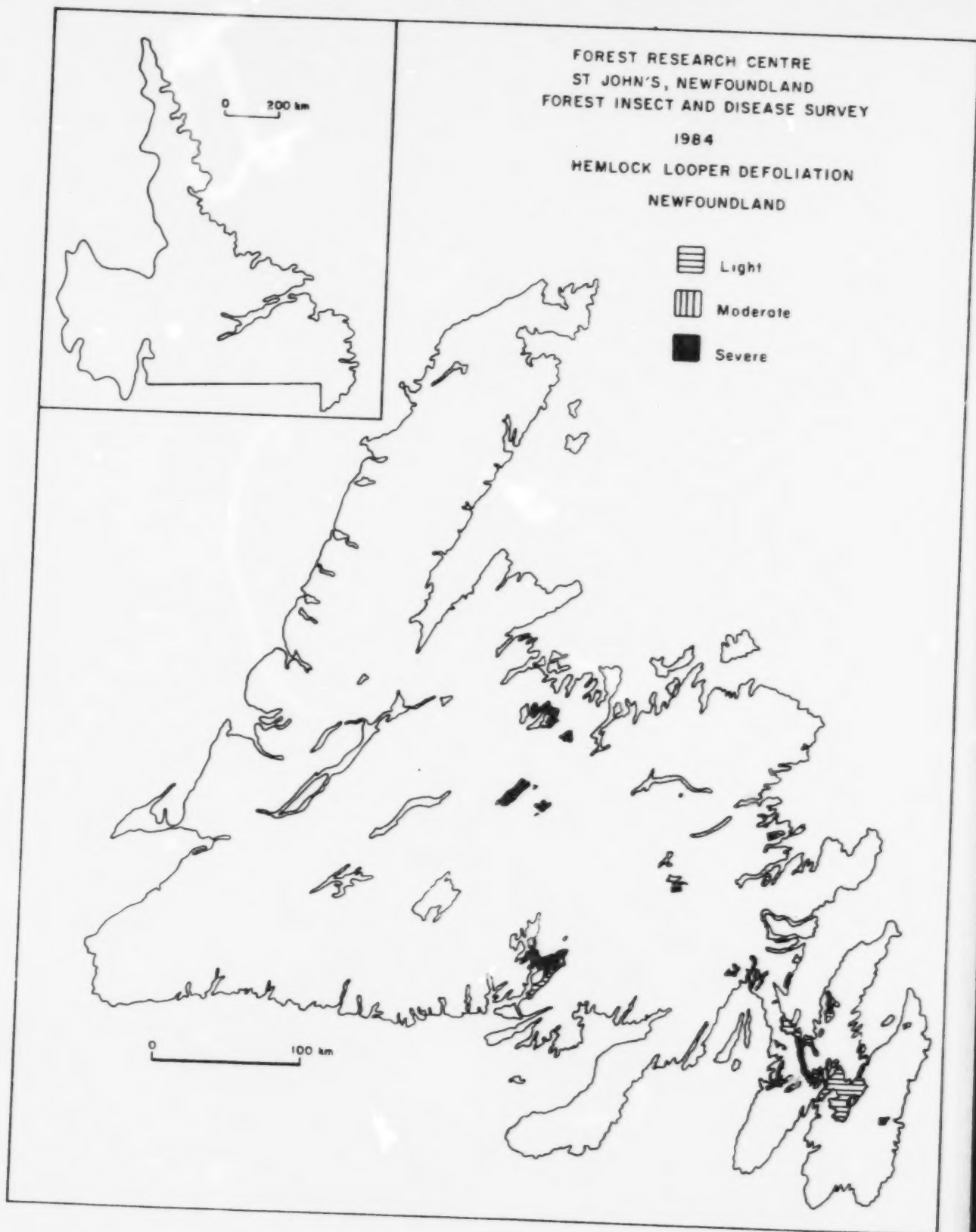


Figure 6. Areas of hemlock looper defoliation in Newfoundland in 1984.

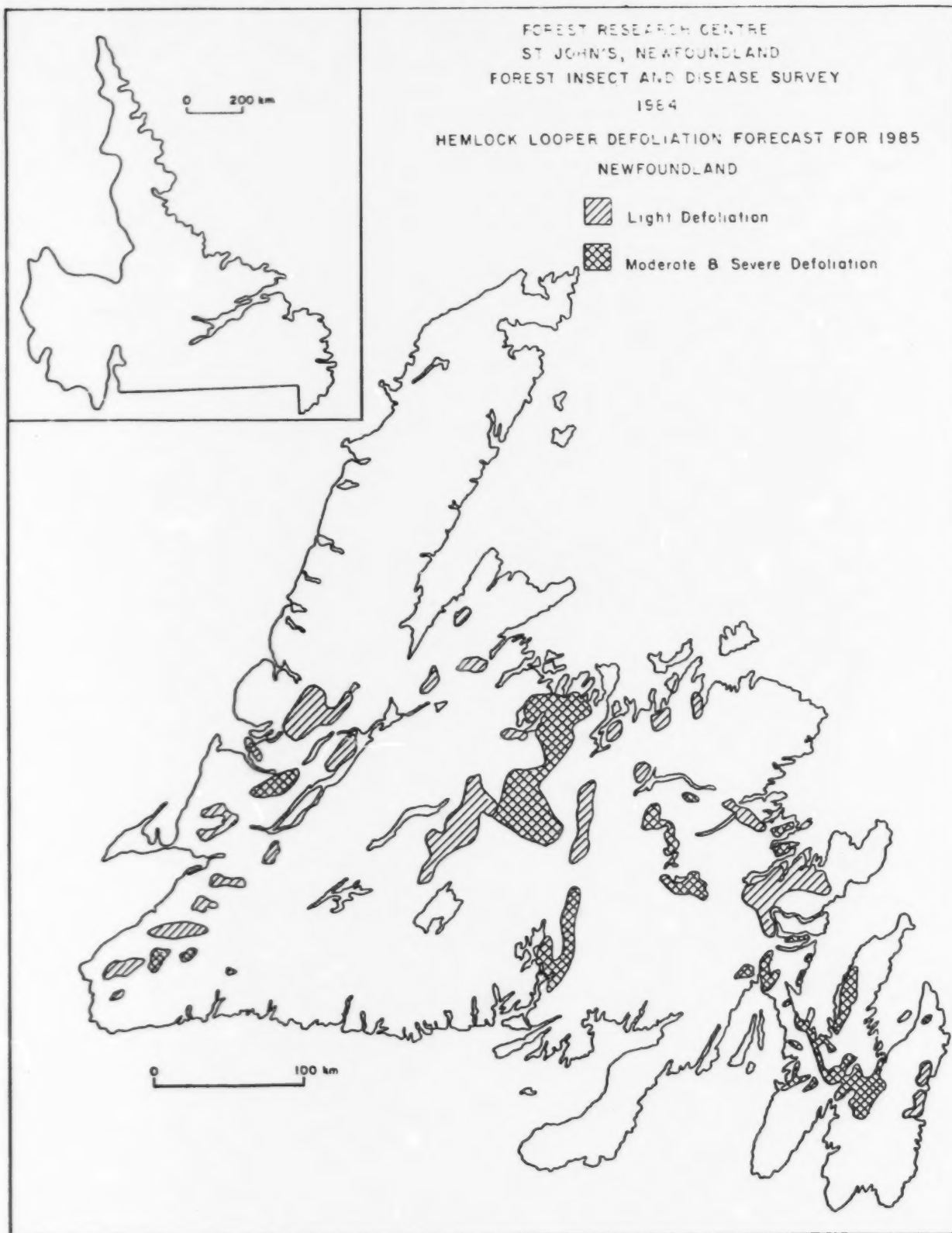


Figure 7. Areas of hemlock looper defoliation forecast for 1985 in Newfoundland.

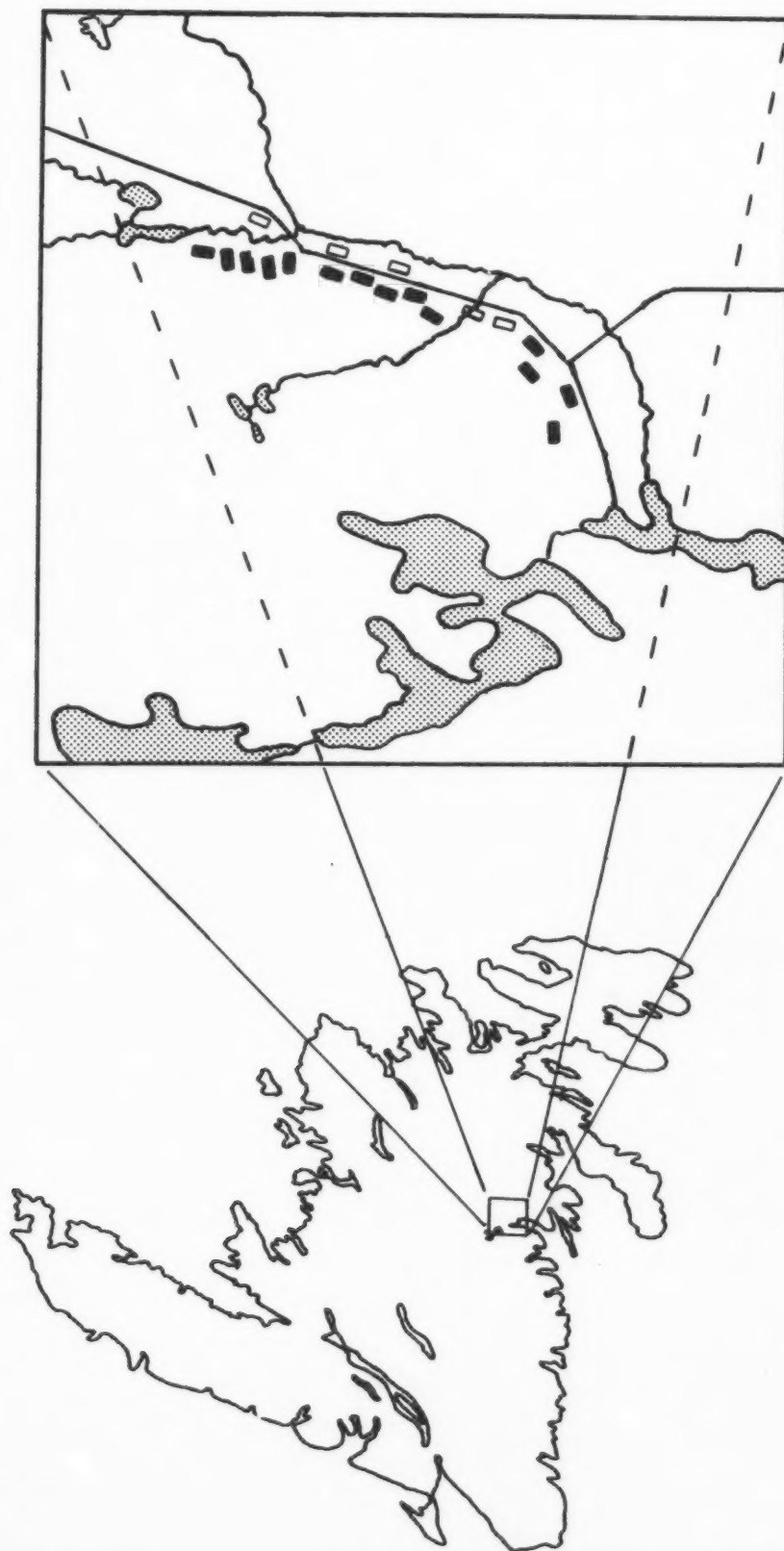


Figure 8. Experimental area for testing effectiveness of insecticides against the hemlock looper in Newfoundland in 1985. Solid rectangles = treatment plots, open rectangles = control plots.

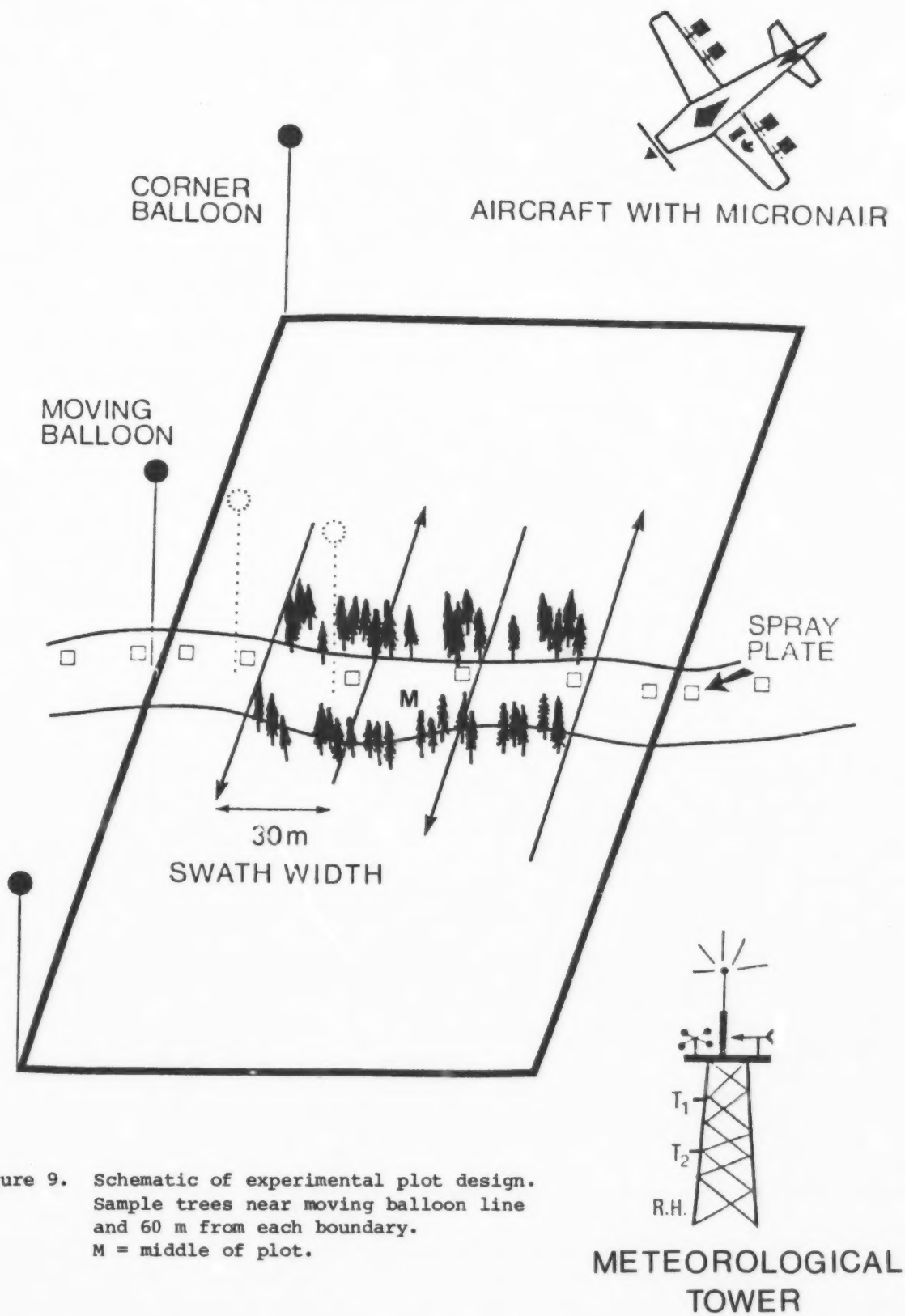


Figure 9. Schematic of experimental plot design. Sample trees near moving balloon line and 60 m from each boundary. M = middle of plot.



Figure 10. Piper Pawnee Aircraft used in experimental spraying against the hemlock looper in Newfoundland in 1985.

Figure 11. AU 5000 Micronair atomizer used in experimental spraying in Newfoundland in 1985.



Figure 12. "Beating" branches over a ground cloth to collect and sample hemlock looper larvae.

Figure 13. Sampling for hemlock looper larvae with pole pruner and basket.

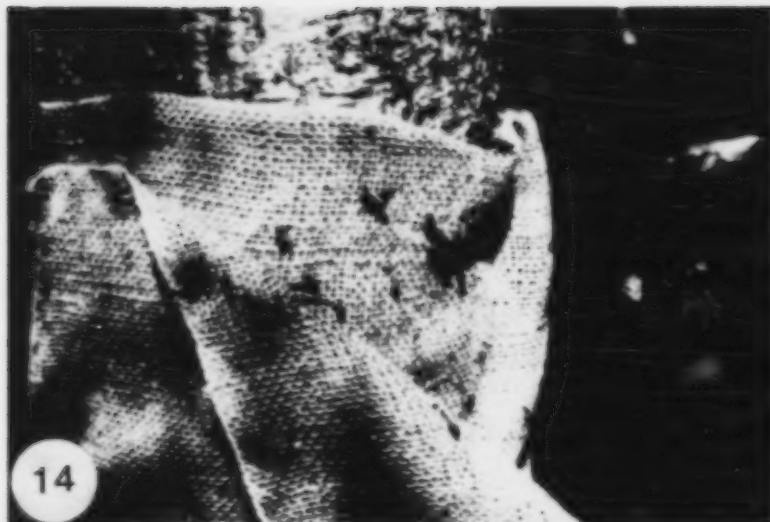


Figure 14. Burlap trap for hemlock looper larvae on bole of balsam fir.

Figure 15. Removing burlap trap containing hemlock looper pupae.

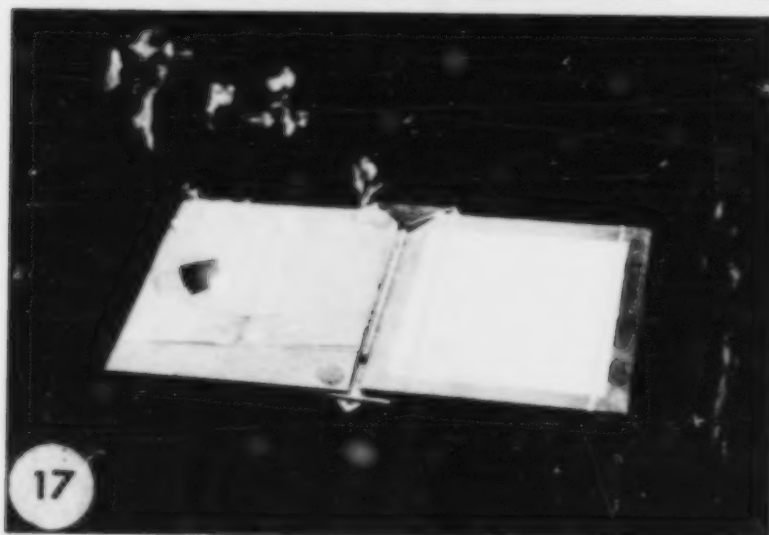
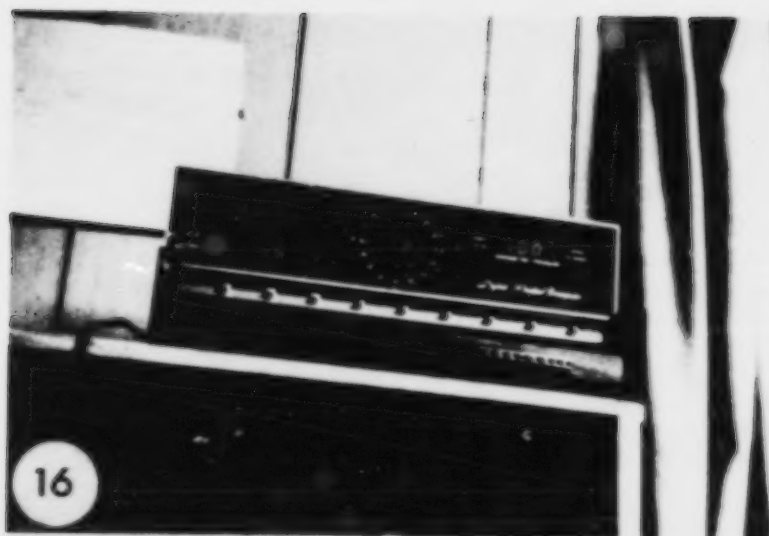


Figure 16. Heathkit weather computer used to monitor weather parameters during experimental sprays against the hemlock looper in Newfoundland in 1985.

Figure 17. Ground unit used to measure spray deposit: white Kromekote^R card and two glass plates.

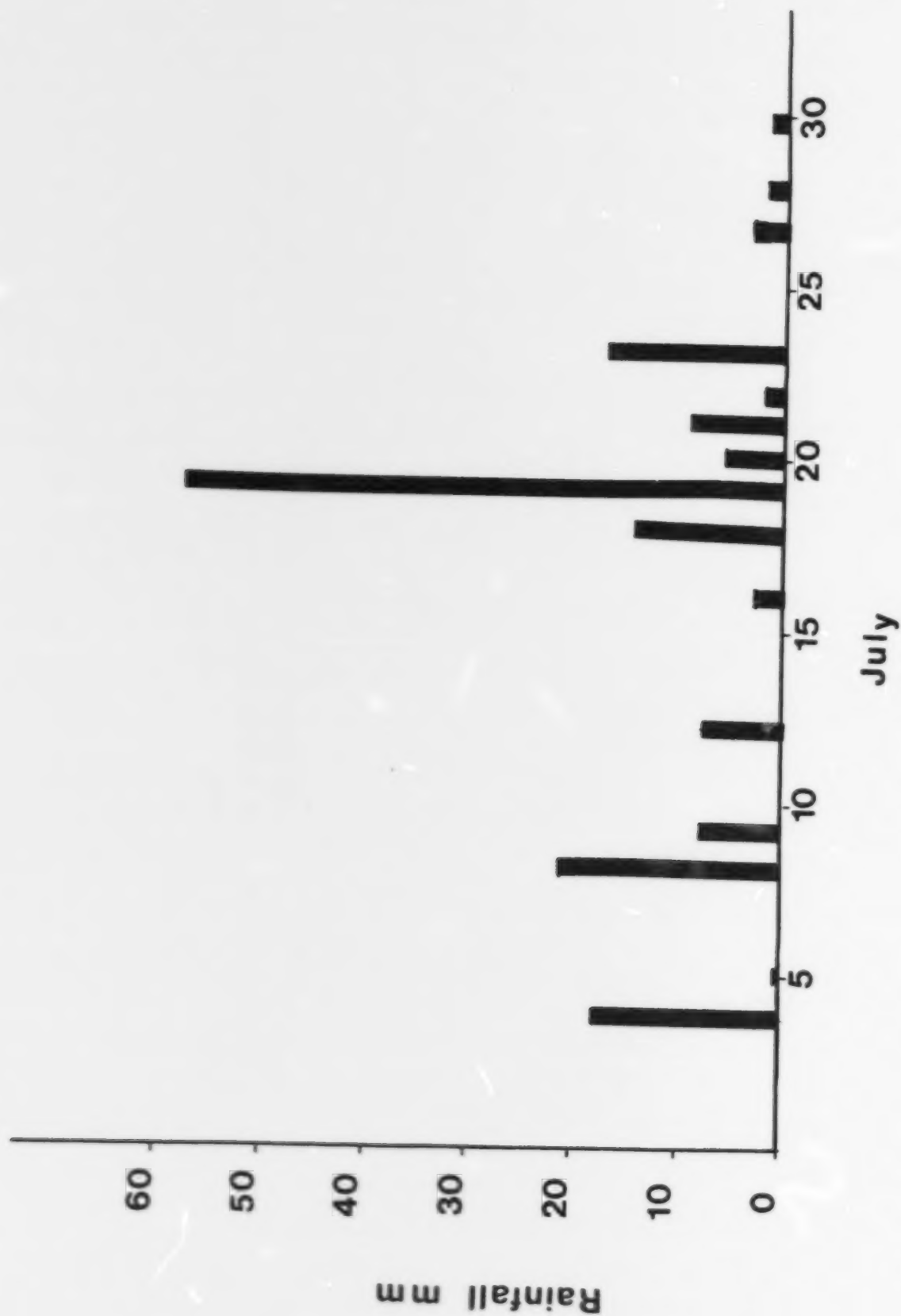


Figure 18. Daily rainfall in July 1985 at Bay d'Espoir, Newfoundland.

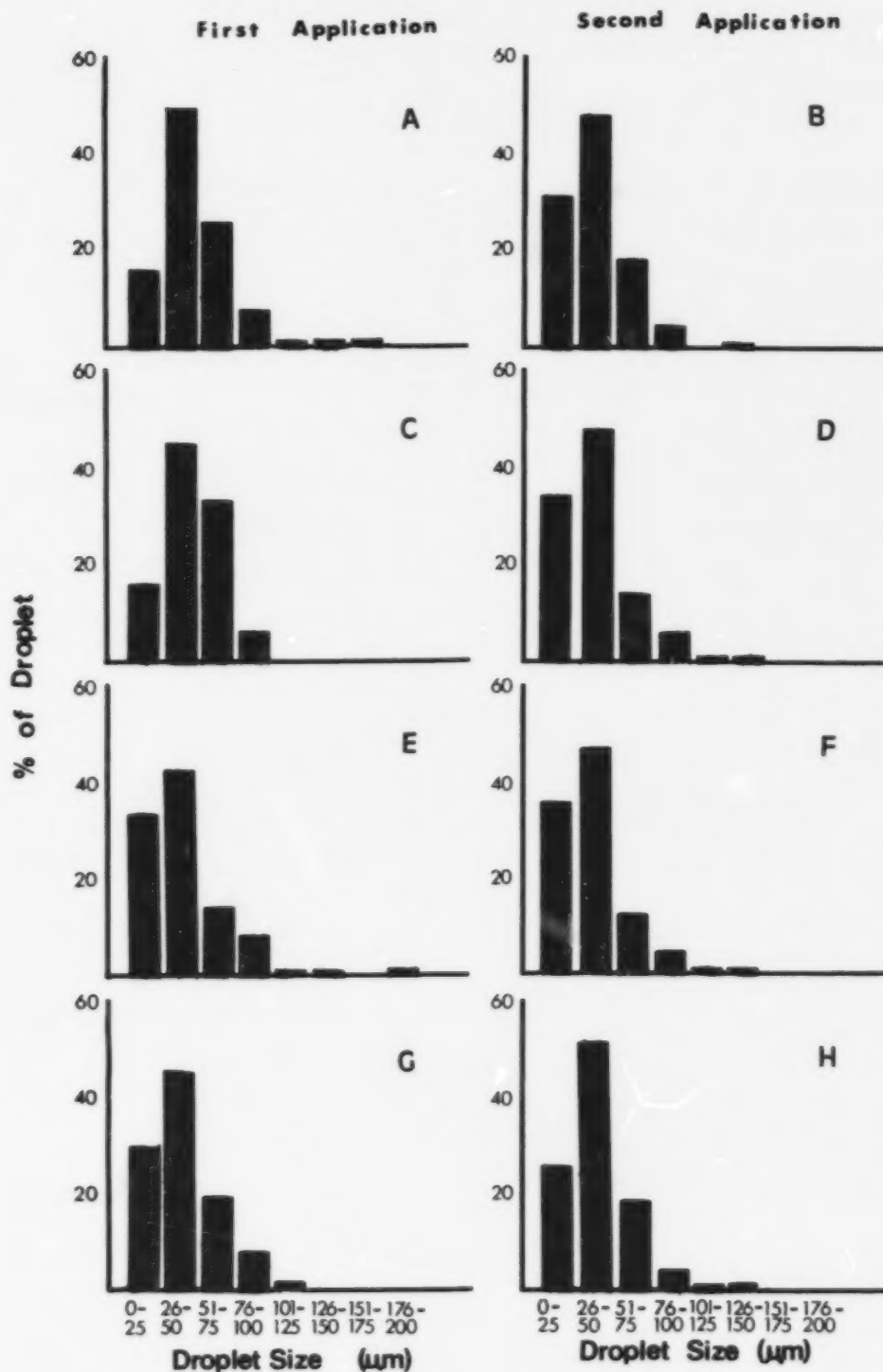


Figure 19. *Bacillus thuringiensis* deposit spectra on balsam fir foliage by droplet-diameter classes:

A, B - Futura, 20 BIU, first and second application;
 C, D - Futura, 30 BIU, first and second application;
 E, F - Thuricide 48LV, 30 BIU, first and second application;
 G, H - Thuricide 64B, 30 BIU, first and second application.

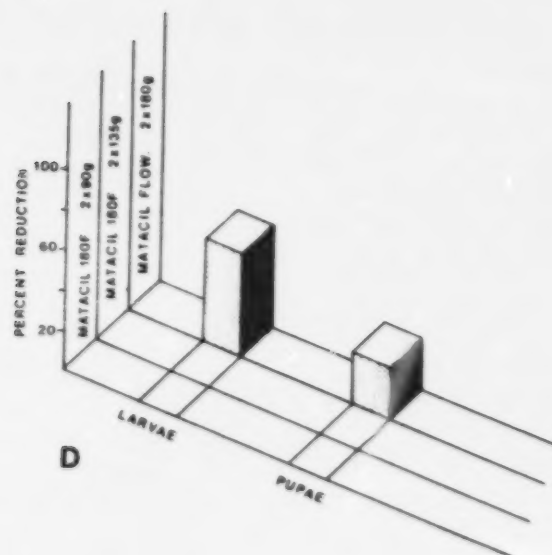
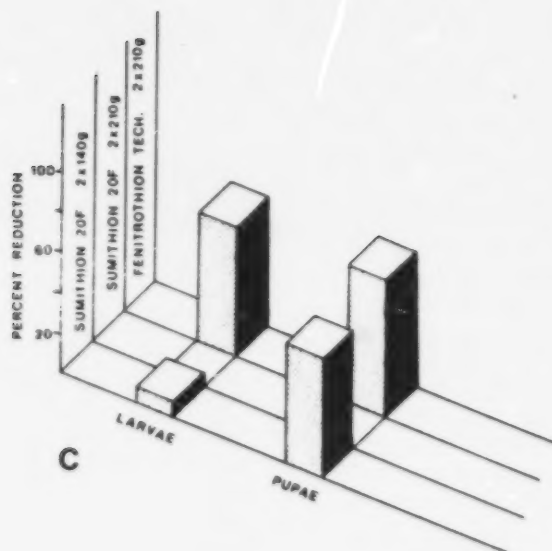
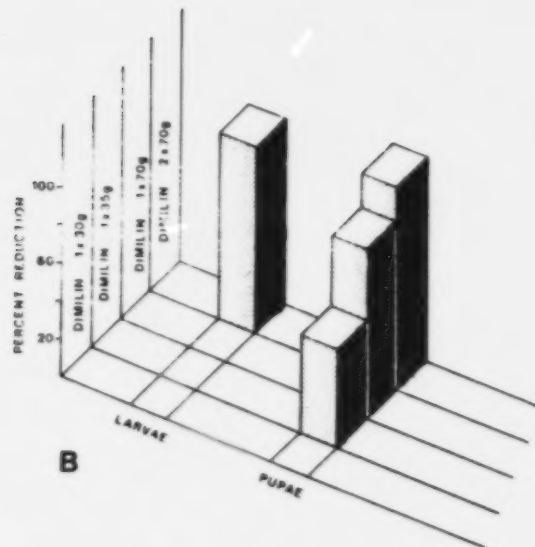
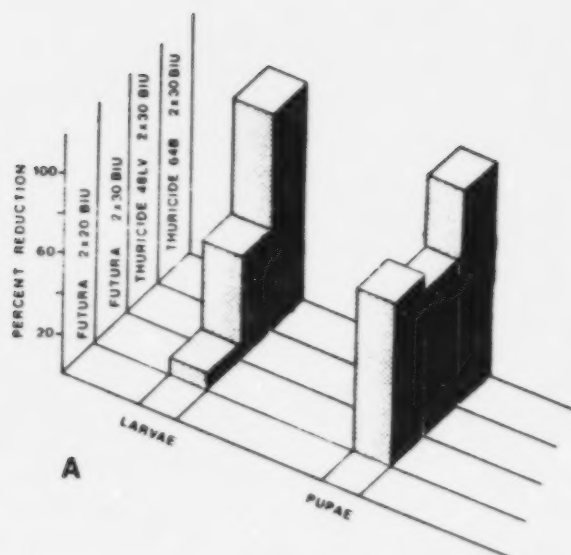
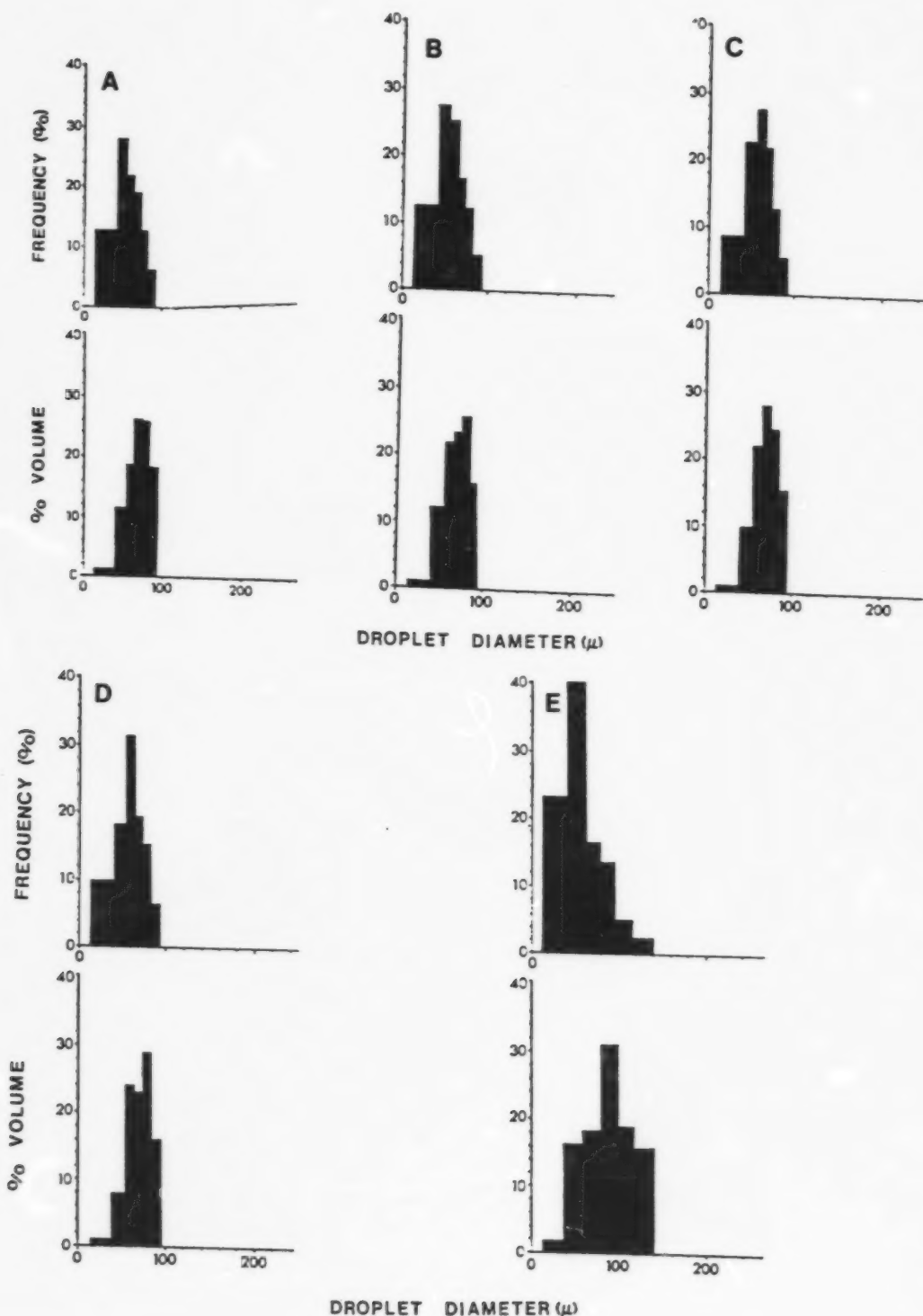


Figure 20. Reductions in hemlock looper populations following aerial application of (A) *Bacillus thuringiensis*, (B) Dimilin®, (C) Sumithion®, and (D) Matacil®.

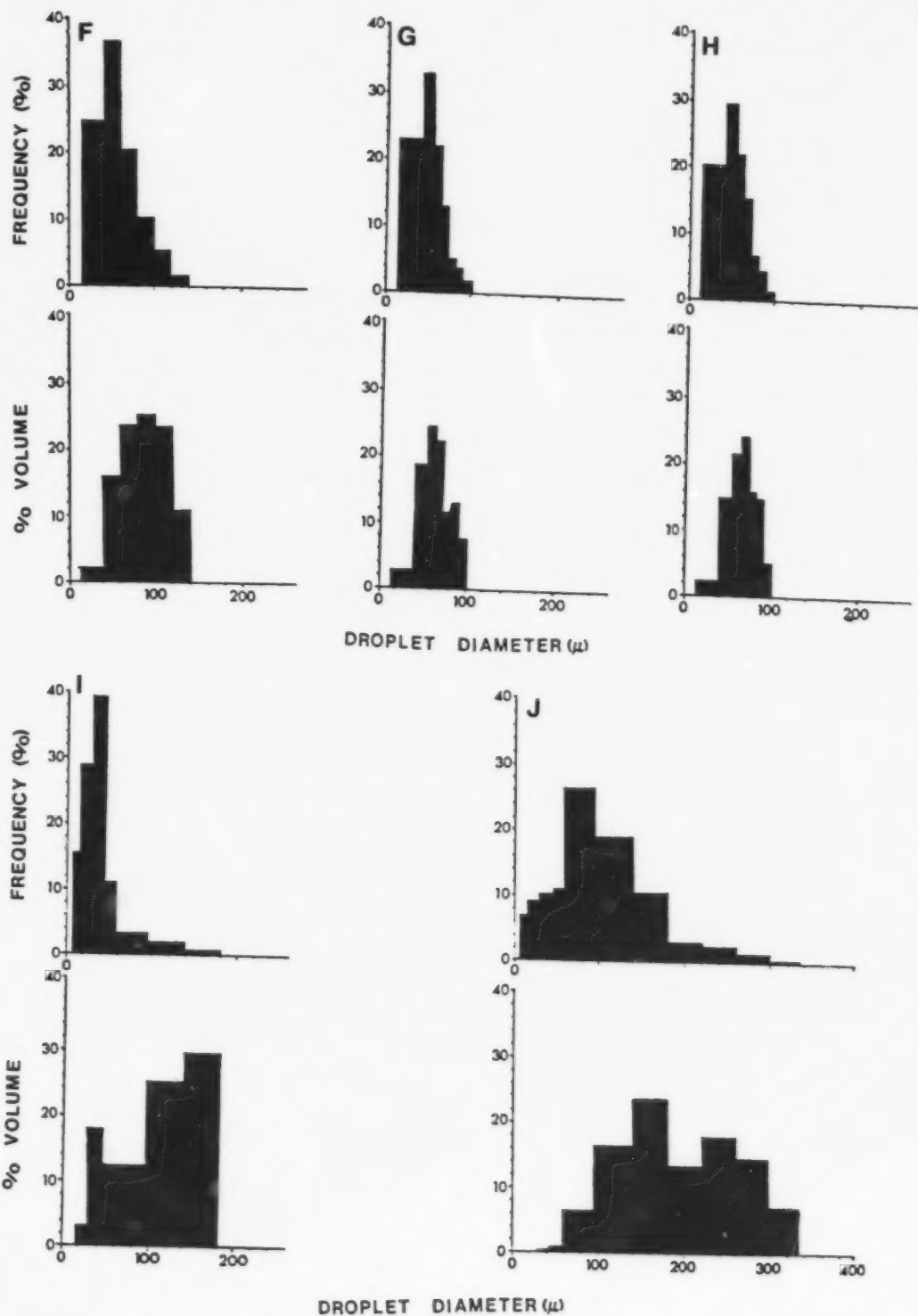
APPENDIX I

Frequency distribution of droplet-diameter classes on
Kromekote® cards by number of droplets and by volume of droplets.

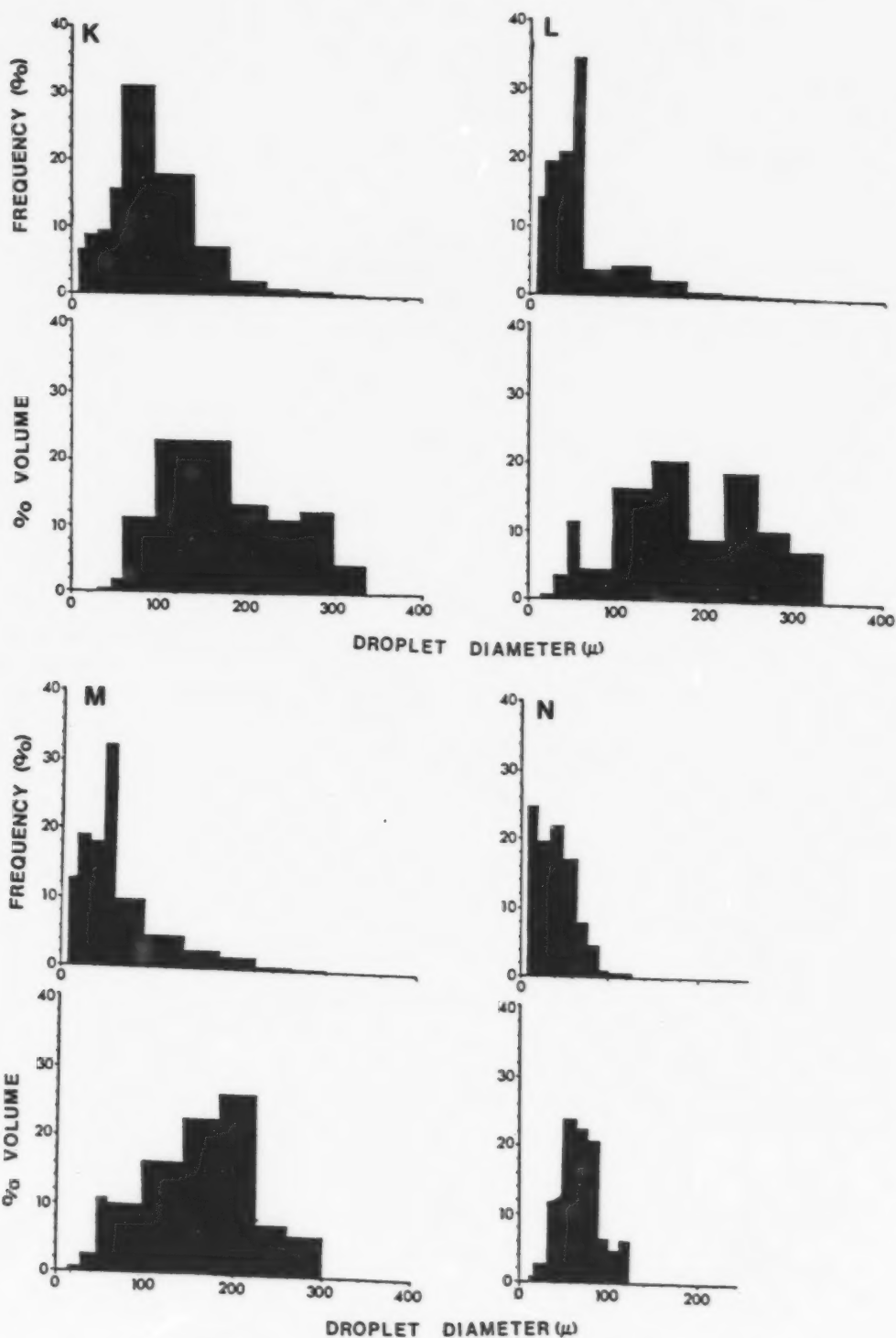
Droplet diameter classes in units of 25 μ (0-25, 26-50, 51-75, etc.)



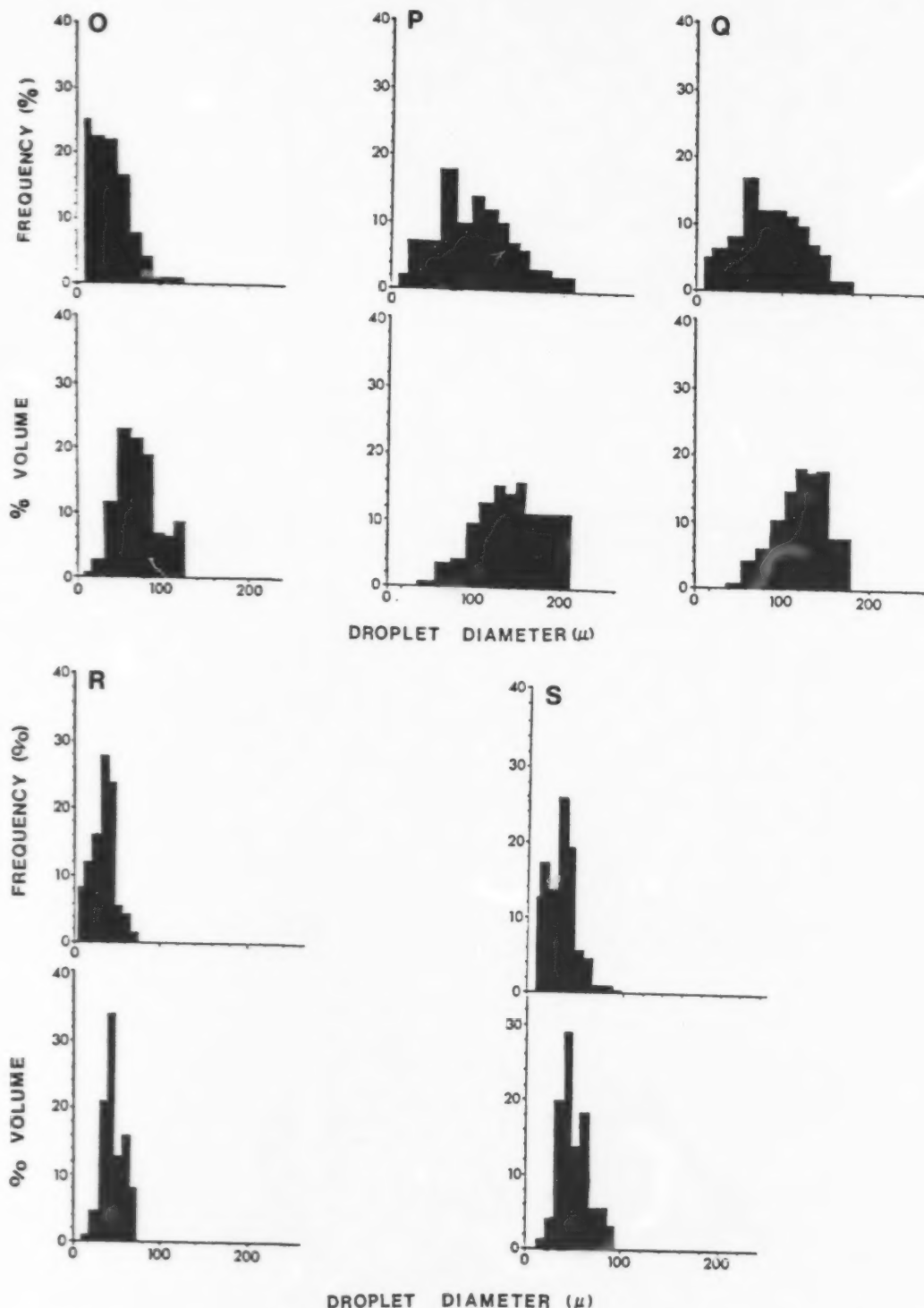
Appendix I. Frequency distribution of droplet-diameter classes of aerial application of insecticides. A. Plot 5, Futura at 20 BIU, first application. B. Plot 5, Futura at 20 BIU, second application. C. Plot 6, Futura at 30 BIU, first application. D. Plot 6, Futura at 30 BIU, second application. E. Plot 18, Thuricide 48LV at 30 BIU, first application.



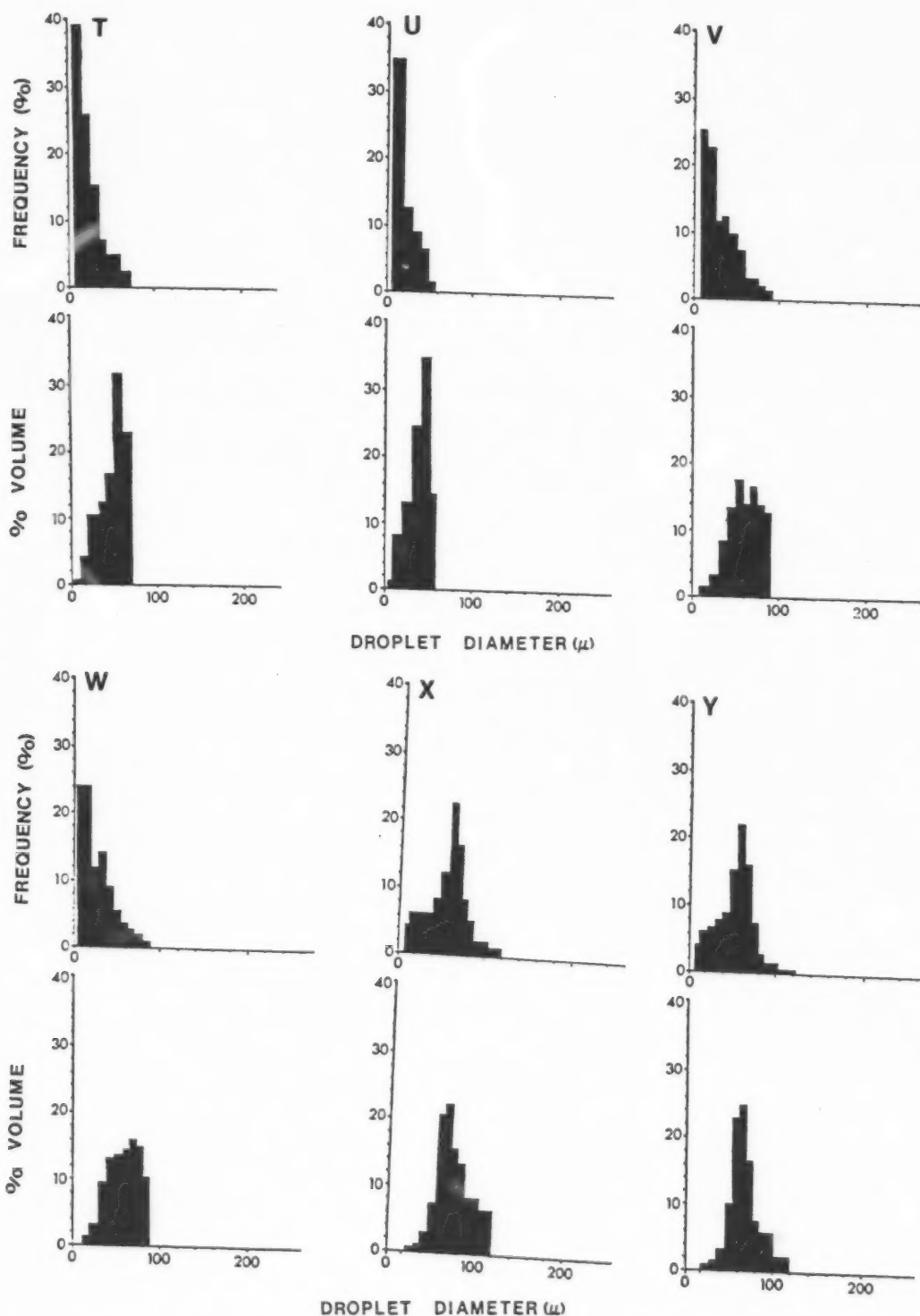
Appendix I. Frequency distribution of droplet-diameter classes of aerial application of insecticides. F. Plot 18, Thuricide 48LV at 30 BIU, second application. G. Plot 14, Thuricide 64B at 30 BIU, first application. H. Plot 14, Thuricide 64B at 30 BIU, second application. I. Plot 11, Dimilin at 30 g ai/ha. J. Plot 9, Dimilin at 35 g ai/ha.



Appendix I. Frequency distribution of droplet-diameter classes of aerial application of insecticides. K. Plot 10, Dimilin at 70 g ai/ha. L. Plot 16, Dimilin at 70 g ai/ha, first application. M. Plot 16, Dimilin at 70 g ai/ha, second application. N. Plot 12, Sumithion 20F at 140 g ai/ha, first application.



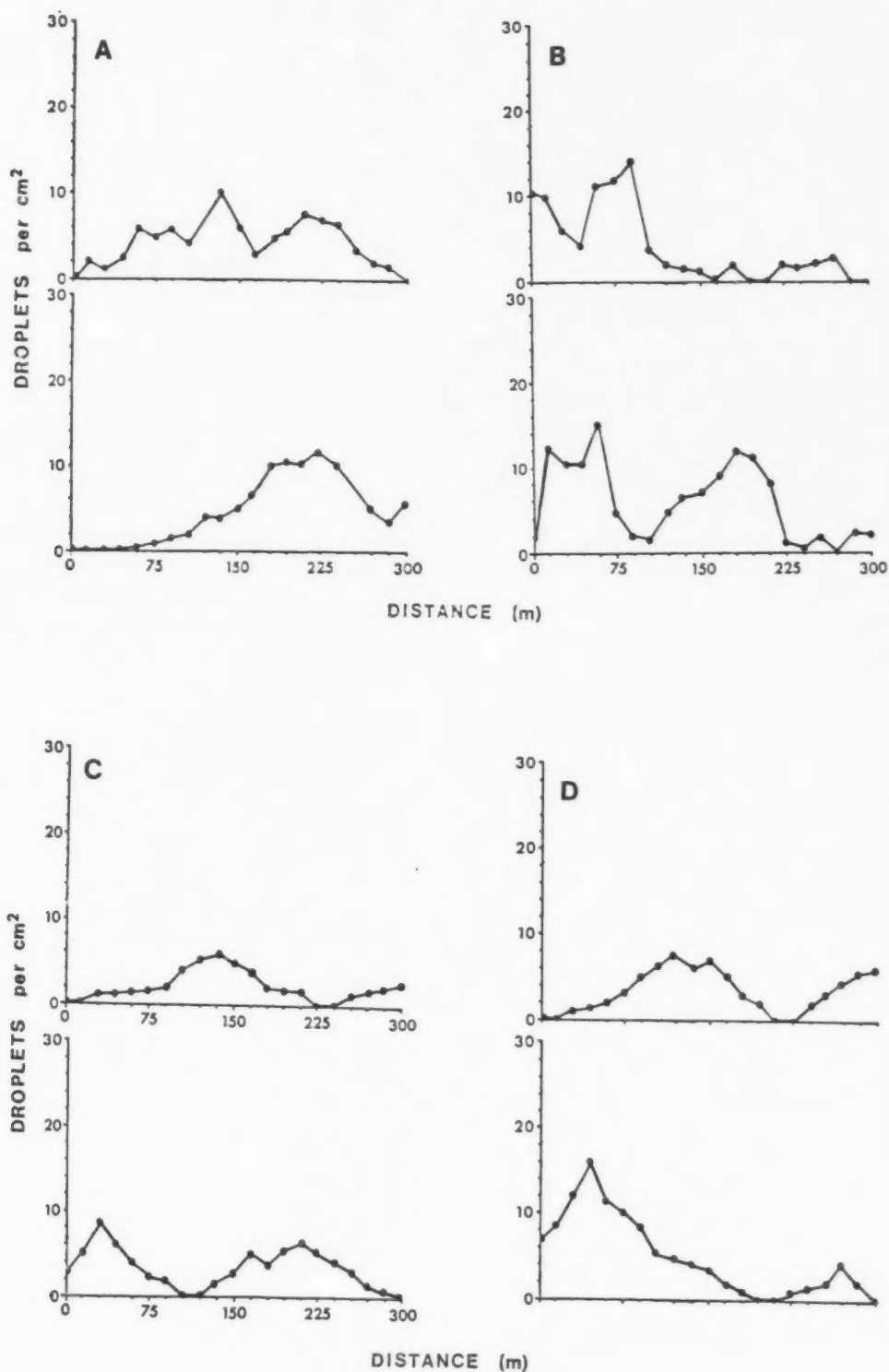
Appendix I. Frequency distribution of droplet-diameter classes of aerial application of insecticides. O. Plot 12, Sumithion 20F at 140 g ai/ha, second application. P. Plot 13, Sumithion 20F at 210 g ai/ha, first application. Q. Plot 13, Sumithion 20F at 210 g ai/ha, second application. R. Plot 17, Sumithion Technical at 210 g ai/ha, first application. S. Plot 17, Sumithion Technical at 210 g ai/ha, second application.



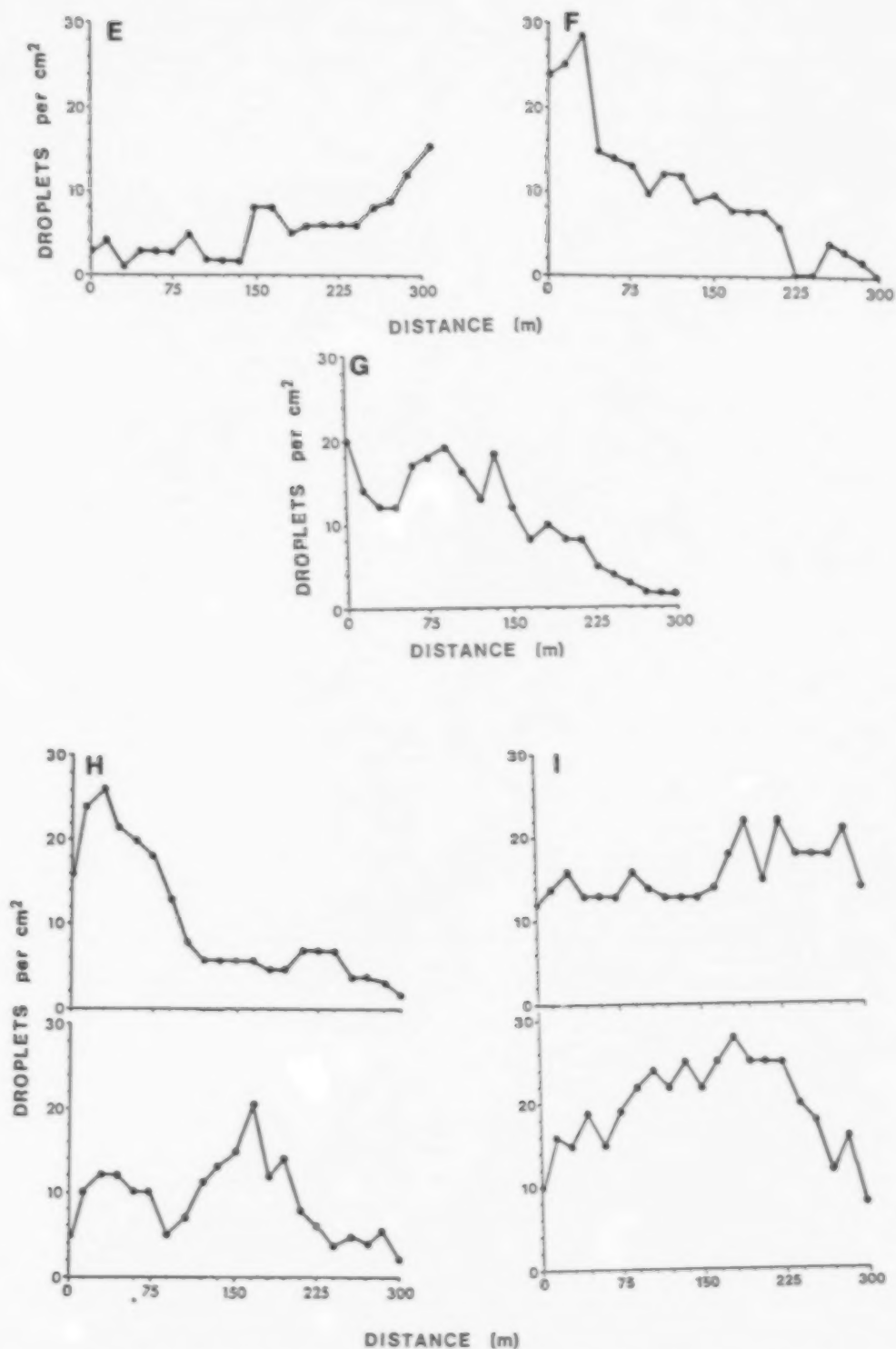
Appendix I. Frequency distribution of droplet diameter classes of aerial application of insecticides. T. Plot 7, Matacil 180F at 90 g ai/ha, first application. U. Plot 7, Matacil 180F at 90 g ai/ha, second application. V. Plot 8, Matacil 180F at 135 g ai/ha, first application. W. Plot 8, Matacil 180F, at 135 g ai/ha, second application. X. Plot 15, Matacil 180F at 180 g ai/ha, first application. Y. Plot 15, Matacil 180F at 180 g ai/ha, second application.

APPENDIX II

Droplet density (per cm^2) on Kromekote® cards placed near ground at 15 m intervals across spray plots.

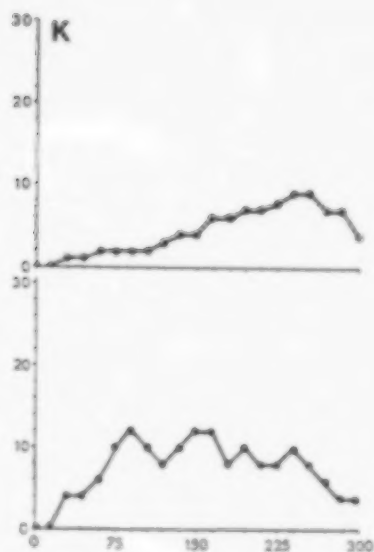
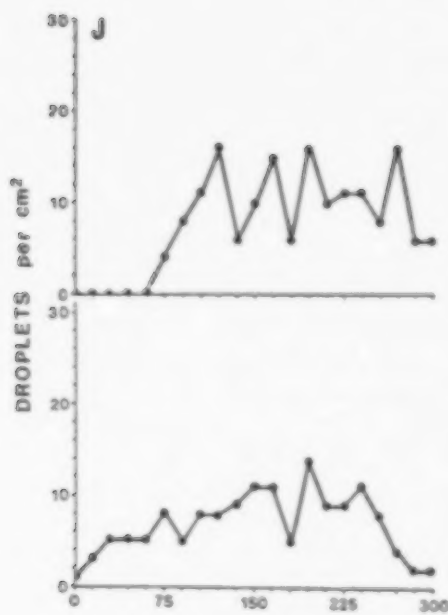


Appendix II. Droplet density at 15 m intervals across sprayed plot; top = first application, bottom = second application. A. Plot 5, Futura at 20 BIU. B. Plot 6, Futura at 30 BIU. C. Plot 18, Thuricide 48LV at 30 BIU. D. Plot 14, Thuricide 64B at 30 BIU.

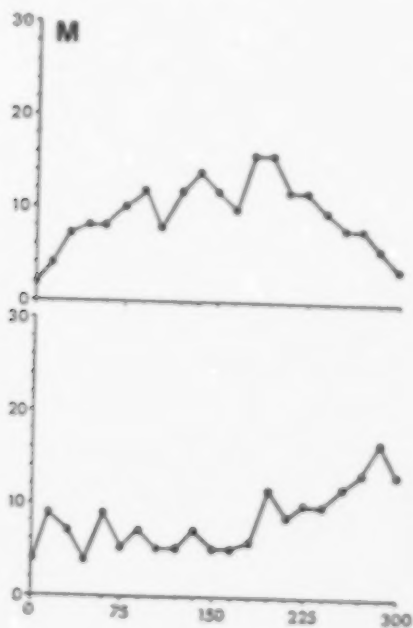
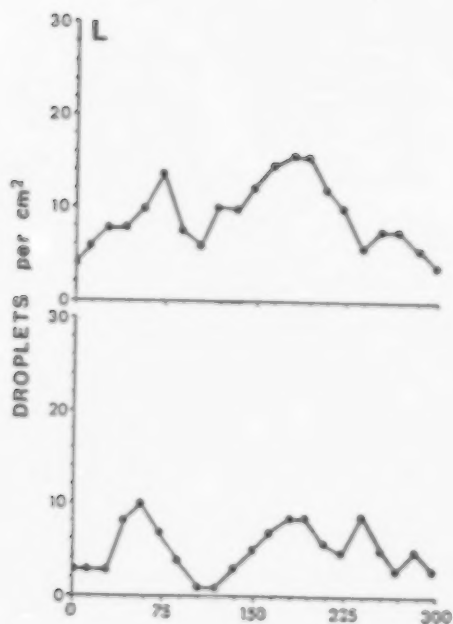


Appendix II. Droplet density at 15 m intervals across sprayed plot.

E. Plot 11, Dimilin at 30 g ai/ha. F. Plot 9, Dimilin at 35 g ai/ha. G. Plot 10, Dimilin at 70 g ai/ha. H. Dimilin at 70 g ai/ha; top = first application, bottom = second application. I. Sumithion 20F at 140 g ai/ha; top = first application, bottom = second application.

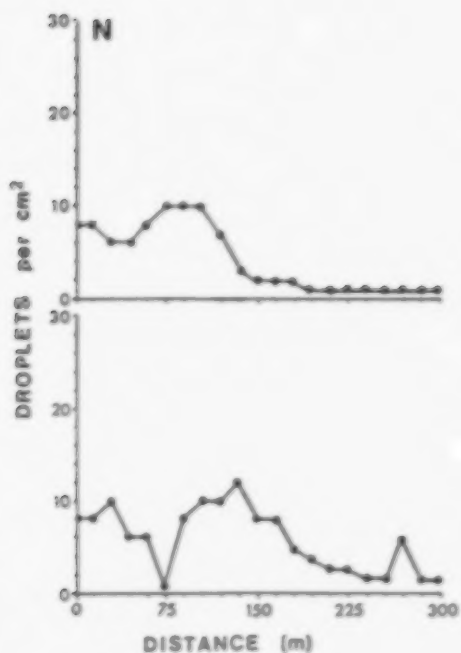


DISTANCE (m)



DISTANCE (m)

Appendix II. Droplet density at 15 m intervals across sprayed plot; top = first application, bottom = second application. J. Plot 13, Sumithion 20F at 210 g ai/ha. K. Plot 17, Sumithion Technical at 210 g ai/ha. L. Plot 7, Matacil 180F at 90 g ai/ha. M. Plot 8, Matacil 180F at 135 g ai/ha.



Appendix II. Droplet density at 15 m intervals across sprayed plot.
N. Plot 15, Matacil 180F at 180 g ai/ha; top = first application,
bottom = second application.

Appendix III. Reductions in hemlock looper pupal numbers following aerial applications of insecticides adjusted by percent disease of late-instar larvae in Newfoundland in 1985.

Plot No.	Number of looper		Percent disease	Adjusted pupal trap count*	Adjusted population reduction(%)
	Pre-spray	Pupal trap			
<u>Bacillus thuringiensis</u>					
(5)	257	524	1	529	
B	222	184	4	191	0
(6)	80	20	1	20	
A	107	164	12	186	86
(18)	66	15	21.9	19	
A	107	164	12	186	84
(14)	1225	4	0		
F	275	355	20	444	(= 100)
<u>Dimilin</u>					
(11)	270	369	9.1	369	
B	222	184	3.0	191	0
(9)	100	73	5	77	
A	107	164	12	186	56
(10)	161	11	0	11	
B	222	184	3.0	191	92
(16)	1386	2	0	0	
F	219	355	20	444	(= 100)
<u>Fenitrothion</u>					
(12)	86	71	15	84	
A	107	164	12	186	44
(13)	142	424	7	456	
C	278	274	12	311	0
(17)	829	279	51	569	
F	275	355	20	444	57
<u>Matacil</u>					
(7)	48	329	0	329	
A	107	164	12	186	0
(8)	54	205	11	230	
A	107	164	12	186	0
(15)	204	184	30	263	
F	275	355	20	444	20

*Adjusted pupal count = $\frac{\text{Pupal trap count}}{100 - (\% \text{ diseased larvae})} \times 100$

Appendix IV. Number of trees in various defoliation classes, average defoliation and aerial estimates of defoliation in experimental plots sprayed to control the hemlock looper in Newfoundland in 1985.

Plot No.	Treatment	Dosage	Number of Trees in Tree Defoliation Class*						Average Defoliation	Aerial Defoliation Estimate
			1	2	3	4	5	6		
5	Futura	2 x 20 BIU	8	32	0	0	0	0	10	Light
6	Futura	2 x 30 BIU	40	0	0	0	0	0	0	Nil
18	Thuricide 48LV	2 x 30 BIU	40	0	0	0	0	0	0	Nil
14	Thuricide 64B	2 x 30 BIU	0	14	13	10	3	0	39	Severe
11	Dimilin	1 x 30 g ai/ha	0	40	0	0	0	0	2	Nil
9	Dimilin	1 x 35 g ai/ha	0	39	1	0	0	0	2	Nil
10	Dimilin	1 x 70 g ai/ha	0	40	0	0	0	0	2	Nil
16	Dimilin	2 x 70 g ai/ha	0	1	5	22	12	0	66	Moderate
12	Sumithion 20F	2 x 140 g ai/ha	0	40	0	0	0	0	13	Nil
13	Sumithion 20F	2 x 210 g ai/ha	0	40	0	0	0	0	13	Nil
17	Sumithion Tech.	2 x 210 g ai/ha	0	5	14	12	9	0	53	Moderate
7	Matacil 180F	2 x 90 g ai/ha	0	40	0	0	0	0	2	Nil
8	Matacil 180F	2 x 135 g ai/ha	0	40	0	0	0	0	2	Nil
15	Matacil 180F	2 x 180 g ai/ha	11	12	12	4	1	0	24	Moderate
A	Control	-	0	39	1	0	0	0	2	Nil
B	Control	-	0	40	0	0	0	0	2	Nil
C	Control	-	0	40	0	0	0	0	2	Nil
D	Control	-	8	36	16	0	0	0	17	Light
E	Control	-	2	38	0	0	0	0	12	Light
F	Control	-	16	11	9	4	0	0	18	Moderate

*Defoliation classes 1 = 0%, 2 = 1-25%, 3 = 26-50%, 4 = 51-75%, 5 = 76-99%, 6 = 100%.